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THE CARPENTER & JOINER'S ASSISTANT.

Drawn by A. Maclure. Engraved by J.H. Le Keux.

CENTRING FOR THE BALLOCHMYLE VIADUCT.

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THE

CARPENTER AND JOINER'S ASSISTANT.

BEING A COMPREHENSIVE TREATISE

ON THE

SELECTION, PREPARATION, AND STRENGTH OF MATERIALS, AND THE MECHANICAL PRINCIPLES OF FRAMING,

WITH THEIR APPLICATION IN CARPENTRY, JOINERY, AND HAND-RAILING;

ALSO, A COURSE OF INSTRUCTION IN

PRACTICAL GEOMETRY, GEOMETRICAL LINES, DRAWING, PROJECTION, AND PERSPECTIVE; AND AN ILLUSTRATED GLOSSARY OF TERMS USED IN ARCHITECTURE AND BUILDING.

BY

JAMES NEWLANDS,

BOROUGH ENGINEER OF LIVERPOOL.

Illustrated by an Extensive Series of Plates and many Hundred Engravings on Wood.

Lucem Libris Disseminamus

LONDON:
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PREFACE.

The Framing of Timber for structural purposes may be regarded both as a mechanical and as a liberal art. As a mechanical art, it embraces the knowledge of the various ways of executing different works, of the processes of fashioning timber, of the tools which have to be used, and the manner of handling them. As a liberal art, it includes a knowledge of geometry, of the principles of mechanics, of the nature and strength of the material, and its behaviour under the strains to which it is subjected.

On all these branches of knowledge there exist justly esteemed Treatises in our own and other languages. The labours of Barlow, Emy, Jousse, Robison, Rondelet, Nicholson, Tredgold, and many others, are devoted to elucidating the principles of the arts of CARPENTRY and JOINERY; and there are also many useful compilations, foremost among them that of Krafft, the object of which is to present practical examples of the application of these principles. The works of these authors, however, are either too costly to be within the reach of the workman, or the subject is treated in a manner which presupposes greater knowledge of mathematical science than he is likely to possess, or they are written in a foreign language. Further, the information which he seeks is scattered through many separate treatises, none of which singly contains all that he requires to know.

The object of the present Publication is to provide, in a compendious form and in plain language, a Complete and Practical Course of Instruction in the PRINCIPLES of Carpentry and Joinery, with descriptions and representations of a selection of works actually executed, to illustrate the state of these arts at the present time, and to serve as guides in preparing new designs.

The CARPENTER AND JOINER'S ASSISTANT was projected by Mr. John White, author of *Rural Architecture,* who prepared the greater number of the Drawings for the Plates, but died before he could supply any portion of the Text. The task, therefore, of completing the series of Drawings and preparing the Text devolved on the present Editor, who, while availing himself of Mr. White's labours, has endeavoured to expand the work into a systematic and comprehensive Treatise.

With this view the Work is divided into eight parts. The *First Part* is devoted to Practical Geometry, teaching various methods of constructing the angles and the rectilineal and curvilinear figures required in the daily practice of the draughtsman. The *Second Part* teaches the nature and use of the various kinds of Drawing Instruments. The *Third Part* is devoted to Stereography, comprehending the projection of lines, surfaces, and solids, and the application of this projection to the problems of Descriptive Carpentry in groins, pendentives, domes, niches, angle-brackets, roofs, hip-roofs, &c. These three parts thus form A COMPLETE TREATISE ON LINES, a knowledge of which is an essential preliminary to the study of Carpentry and Joinery. The *Fourth Part* treats of the physiology, growth, development, and diseases of Timber trees; of the mode of felling, squaring, and preparing timber for use, and of increasing its durability. It includes a description of the nature, properties, and uses of the various

timber trees which in this country are employed by the Carpenter and Joiner; and it elucidates so much of the principles of the composition and resolution of forces, and of the strength and strain of materials, as belongs to Theoretical Carpentry. In the *Fifth Part* are presented examples of the construction of timber roofs, domes, and spires; of the framing of timber, the formation of joints, straps, truss girders, floors, partitions, timber houses, bridges, centres, and field, park, and dock gates. The *Sixth Part* is devoted to the illustration of Joinery; comprehending the mouldings used, the formation of joints, gluing up of columns, &c., framing and finishing of doors, windows, and skylights, and the various methods of hinging. The *Seventh Part* treats of Stairs, Staircases, and Handrailing, and in the latter, which is contributed by Mr. David Mayer, of Cheltenham, the author develops simple methods of getting out the wreath by one bevel and squared ordinates, the advantages of which he has tested in a long course of practice. The *Eighth Part* advances the student in his knowledge of Drawing, by instruction in the Projections of Shadows, in the method of making Finished Drawings, and in Perspective and Isometrical Projection. To these is added an Index and Illustrated Glossary of the Terms used in Architecture and Building.

The number and character of the Illustrations form a prominent feature of the present Work. They consist of above Eight Hundred Geometric, Constructive, and Descriptive Figures interspersed throughout the text, and One Hundred and Fifteen Plates, containing upwards of One Thousand Figures. The Cuts and Plates combined, comprise, it is believed, a larger number of Illustrations than has hitherto been embodied in any similar treatise published in this country; and by incorporating so large a proportion of them in the text, in place of greatly increasing the number of separate Plates, the double advantage to the purchaser has been gained of ready and convenient reference from the text to the figures, and of a considerable modification in his favour in the total cost of the Work.

It is impossible in a work like this to quote all the sources of information. Frequent references to authorities are given in the text; but in addition to these, it ought to be stated that the sections on Projection and Perspective are based on J. B. Cloquet's *Nouveau Traité Elémentaire de Perspective.*

The Editor has endeavoured to render the Work throughout essentially practical in its character, elucidating the principles and rules not by lengthy demonstrations, but by showing their application in frequent examples.

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THE

CARPENTER AND JOINER'S ASSISTANT.

PART FIRST.

PRACTICAL GEOMETRY.

Geometry is that branch of mathematical science which demonstrates the properties and relative magnitudes of extended things; that is, of lines, surfaces, and solids. It also teaches the drawing of lines and angles, and the construction of all right-lined and curvilineal surfaces and solids; that is, of figures which have length, or which have length and breadth, or length, breadth, and thickness.

Geometry is divided into different branches or departments, as *Elementary* and *Higher Geometry*. Also into *Theoretical* and *Practical Geometry*.

Elementary Geometry treats of the properties and magnitudes of straight lines, of the circle, and of circular lines, and figures formed of such lines; and may thus be considered either as theoretical or practical.

The Higher Geometry treats of the construction and relative magnitudes of solids, of the properties of the sphere, and of the higher orders of curves.

Theoretical Geometry comprehends the theory or speculative part of the science, and demonstrates the relative positions and properties of lines, as well as of the various figures which are formed by them; evincing the truth or discovering the fallacy on which they are constructed, by means of exact reasoning from established principles laid down as axioms. In this manner, any geometrical proposition can be solved without the aid of compasses or any other instrument. To the architect or mechanic this serves as the groundwork or basis for the practical part of the science.

Practical Geometry, as the term implies, is particularly adapted to practical purposes. Although it is from the application of rules derived from theoretical evidence that a geometrical problem can be solved by means of diagrams only, yet the practical system has been brought to such a degree of simplicity, that a person possessed of ordinary capacity may be able, by perseverance—even without comprehending the theory—to acquire a considerable knowledge of the science, independently of any assistance from a teacher. Nevertheless, a proper understanding of the primary reasoning on which the rules are founded will render the study much more interesting, as well as more satisfactory. Hence those who wish to obtain a proficient knowledge of Practical Geometry will be greatly benefited by an attentive study of Euclid's *Elements*, as the subjects selected for the following course are only such as are peculiarly applicable to mechanical purposes. Being chiefly intended for the instruction of architects, engineers, and, more particularly, uninformed mechanics, all speculative and abstruse propositions are studiously avoided.

GENERAL TERMS USED IN GEOMETRY.

1. A *Definition* is a concise description or explanation of the properties of any term or object. To define anything is to explain its nature or mark its limits.

2. An *Axiom* is a statement of some fact, so self-evident that no process of reasoning or demonstration can make it plainer. It is an established principle, admitting of no refutation.

3. A *Postulate* is a position supposed or assumed to be practicable; or it is a demand that certain simple operations may be performed. As, for example, 1st, that a straight line may be drawn from any one point to any other point; 2d, that a line may be *produced*, that is, continued or lengthened out at pleasure to any extent; and, 3d, that a circle may be described from any centre, and with any radius, or at any distance from that centre.

4. A *Theorem* is a statement of some truth, or class of truths, to be demonstrated by a process of reasoning deduced from facts already proved by previous theorems or axioms, the truth of which is self-evident.

5. A *Problem* is something proposed to be done, as the construction of a figure, or the solution of a question.

6. A *Lemma* is a proposition assumed in order to simplify the demonstration of a succeeding proposition. As lemmas rather interrupt the connection of a subject, they should never be introduced except when they are absolutely necessary.

7. A *Proposition* is a common term for a theorem, problem, or lemma.

8. A *Corollary* is a consequence which results irresistibly from the doctrine of a preceding proposition.

9. A *Scholium* is an explanatory observation or note added to extend or elucidate some preceding doctrine.

10. A *Demonstration* is the highest degree of evidence, being founded upon previously established facts, so as to convince the inquirer beyond all doubt of the certainty of the truth propounded.

11. A *Direct Demonstration* is a regular chain of reasoning from the premises laid down, or a deduction of one truth from another, till the proposition advanced is clearly established.

12 An *Indirect Demonstration* proves the truth of any doctrine, by showing that some inconsistency would necessarily be involved in the supposition of its being false.

DEFINITIONS.

1. A *Point* has position but not magnitude. Practically, it is represented by the smallest visible mark or dot, but geometrically understood, it occupies no space. The extremities or ends of lines are points; and when two or more lines cross one another, the places that mark their intersections are also points.

2. A *Line* has length, without breadth or thickness, and, consequently, a true geometrical line cannot be exhibited; for however finely a line may be drawn, it will always occupy a certain extent of space.

3. A *Superficies* or *Surface* has length and breadth, but no thickness. For instance, a shadow gives a very good representation of a superficies: its length and breadth can be measured; but it has no depth or substance. The quantity of space contained in any plane surface is called its area.

4. A *Plane Superficies* is a flat surface, which will coincide with a straight line in every direction.

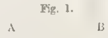
5. A *Curved Superficies* is an uneven surface, or such as will not coincide with a straight line in any direction. By the term surface is generally understood the outside of any body or object; as, for instance, the exterior of a brick or stone, the boundaries of which are represented by lines, either straight or curved, according to the form of the object. We must always bear in mind, however, that the lines thus bounding the figure occupy no part of the surface; hence the lines or points traced or marked on any body or surface, are merely symbols of the true geometrical lines or points.

6. A *Solid* is anything which has length, breadth, and thickness; consequently, the term may be applied to any visible object containing substance; but, practically, it is understood to signify the solid contents or measurement contained within the different surfaces of which any body is formed.

7. *Lines* may be drawn in any direction, and are termed straight, curved, mixed, concave, or convex lines, according as they correspond to the following definitions.

8. A *Straight Line* is one that lies in the same direction between its extremities, and is, of course, the shortest distance between two points, as from A to B, Fig. 1.

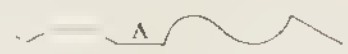
Fig. 1.



9. A *Curved Line* is such that it does not lie in a straight direction between its extremities, but is continually changing by inflection. It may be either regular, as A, or irregular, as B, Fig. 2.

Fig. 2.

Fig. 3



10. A *Mixed* or *Compound Line* is composed of straight and curved lines, connected in any form, as A, Fig. 3.

11. A *Concave* or *Convex Line* (Fig. 4), is such that it

Fig. 4.

Fig. 5.

Fig. 6.

cannot be cut by a straight line in more than two points; the concave or hollow side is turned towards the straight line, while the convex or swelling side looks away from it. For instance, the inside of a basin is concave—the outside of a ball is convex.

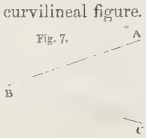
12. *Parallel Straight Lines* have no inclination, but are everywhere at an equal distance from each other; consequently they can never meet, though produced or continued to infinity in either or both directions. Parallel lines may be either straight or curved (Fig. 5), provided they are equally distant from each other throughout their extension.

13. *Oblique* or *Converging Lines* (Fig. 6), are straight lines, which, if continued, being in the same plane, change their distance so as to meet or intersect each other.

14. A *Plane Figure, Scheme, or Diagram,* is the lineal representation of any object on a plane surface. If it is bounded by straight lines, it is called a rectilineal figure; and if by curved lines, a curvilineal figure.

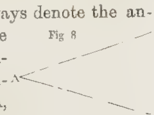
15. An *Angle* is formed by the inclination of two lines meeting in a point: the lines thus forming the angle are called the sides; and the point where the lines meet is called the *vertex* or *angular point.*

Fig. 7.



When an angle is expressed by three letters, as A B C, Fig. 7, the middle letter B should always denote the angular point: where there is only one angle, it may be expressed more concisely by a letter placed at the angular point only, as the angle at A, Fig. 8.

Fig. 8



16. The quantity of an angle is estimated by the arc of any circle contained between the two sides or lines forming the angle; the junction of the two lines, or vertex of the angle, being the centre from which the arc is described. As the circumferences of all circles are proportional to their diameters, the arcs of similar sectors also bear the same proportion to their respective circumferences; and, consequently, are proportional to their diameters, and, of course, also to their radii or semidiameters. Hence, the proportion which the arc of any circle bears to the circumference of that circle, determines the magnitude of the angle. From this it is evident

that the quantity or magnitude of angles does not depend upon the length of the sides or radii forming them, but wholly upon the number of degrees contained in the arc cut from the circumference of the circle by the opening of these lines. The circumference of every circle is divided by mathematicians into 360 equal parts, called degrees; each degree being again subdivided into 60 equal parts, called minutes, and each minute into 60 equal parts, called seconds. Hence it follows, that the arc of a quarter circle or quadrant includes 90 degrees, that is, one-fourth part of 360 degrees. By dividing a quarter circle, that is, the portion of the circumference of any circle contained between two radii forming a right angle, into 90 equal parts, or, as shown in Fig. 9, into nine equal parts of 10 degrees each, then drawing straight lines from the centre through each point of division in the arc, the right angle will be divided into nine equal angles, each containing 10 degrees. Thus, suppose B C the horizontal line, and A B the perpendicular ascending from it, any line drawn from B—the centre from which the arc is described—to any point in its circumference, determines the degree of inclination or angle formed between it and the horizontal line B C. Thus a line from the centre B (Fig. 9), to the tenth degree, separates an angle of 10 degrees, and so on. In this manner the various slopes or inclinations of angles are defined.

Fig. 9

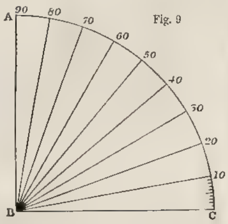


Fig. 10.

Fig. 11.

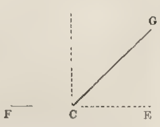
17. A *Right Angle* is produced either by one straight line standing upon another, so as to make the adjacent angles equal (Fig. 10), or by the intersection of two straight lines, so as to make all the four angles equal to one another (Fig. 11).

18. An *Acute Angle* is less than a right angle, or less than 90 degrees, as the angle A B C, Fig. 12.

19. An *Obtuse Angle* is greater than a right angle, or more than 90 degrees, as F C G, Fig. 13.

Fig. 12.

Fig. 13.



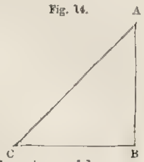
The number of degrees by which an acute angle is less than 90 degrees, is called the complement of the angle. Also, the difference between an obtuse angle and a semicircle, or 180 degrees, is called the supplement of that angle.

Thus, C B D is the complement of the acute angle A B C, in Fig. 12; and G C E is the supplement of the obtuse angle G C F, in Fig. 13.

20. *Plane Figures* are bounded by straight lines, and are named according to the number of sides or angles which they contain. Thus, the space included within three straight lines, and forming three angles, is called a trilateral figure or triangle.

21. A *Right-Angled Triangle* has one right angle: the sides forming the right angle are called the base and perpendicular; and the side opposite the right angle is named the hypotenuse. Thus, in the right-angled triangle A B C (Fig. 14), B C is the base, A B the perpendicular, and A C the hypotenuse. The hypotenuse, or longest side of a right-angled triangle, may also form the base or underline. In that case, the other two sides are called the legs of the triangle.

Fig. 14.



22. An *Equilateral Triangle* is that whose three sides are equal, as in Fig. 15.

Fig. 15.

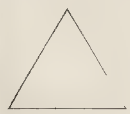
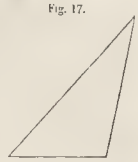


Fig. 16.

Fig. 17.



23. An *Isosceles Triangle* has only two sides equal, as Fig. 16.

24. A *Scalene Triangle* is that whose three sides are all unequal, as shown in Fig. 17.

25. An *Acute-Angled Triangle* has all its angles acute, as those in Figs. 15 and 16.

26. An *Obtuse-Angled Triangle* has one of its angles obtuse, as in Fig. 17. It is obvious from Fig. 17 that a triangle cannot contain more than one obtuse angle.

The triangle is one of the most useful geometrical figures in taking dimensions; for since all figures that are bounded by straight lines are capable of being divided into triangles, and as the form of a triangle cannot be altered without changing the length of some one of its sides, it follows that the true form of any figure can be preserved by having the length of the sides of the different triangles into which it is divided.

27. *Quadrilateral* figures are literally four-sided figures. They are also called quadrangles, because they have four angles.

28. A *Parallelogram* is a figure whose opposite sides are parallel, as A B C D, Fig. 18.

Fig. 18

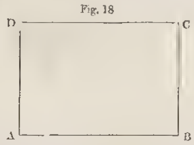
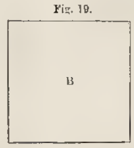


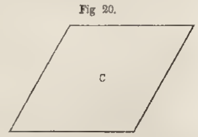
Fig. 19.



29. A *Rectangle* is a parallelogram having four right angles, as A B C D, Fig. 18.

30. A *Square* is an equilateral rectangle, having all its sides equal, as B, Fig. 19.

Fig. 20.



31. An *Oblong* is a rectangle whose adjacent sides are unequal, as the parallelogram A B C D, Fig. 18.

32. A *Rhombus* is an oblique-angled figure, or parallelogram, having four equal sides, whose opposite angles only are equal, as C, Fig. 20.

33. A *Rhomboid* is an oblique-angled parallelogram, of which the adjoining sides are unequal, as D, Fig. 21.

Fig. 21.

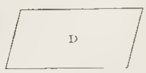


Fig. 22.

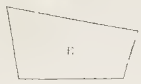


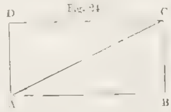
Fig. 23.

34. A *Trapezium* is an irregular quadrilateral figure, having no two sides parallel, as E, Fig. 22.

35. A *Trapezoid* is a quadrilateral figure, which has two of its opposite sides parallel, and the remaining two neither parallel nor equal to one another, as F, Fig. 23.

36. A *Diagonal* is a straight line drawn between two opposite angular points of a quadrilateral figure, or between any two angular points of a polygon. Should the figure be a parallelogram, the diagonal will divide it into two equal triangles, the opposite sides and angles of which will be equal to one another. Let A B C D, Fig. 24, be a parallelogram; join A C, then A C is a diagonal, and the triangles A D C, A B C, into which it divides the parallelogram, are equal.

Fig. 24



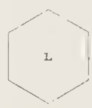
37. A plane figure, bounded by more than four straight lines, is called a *Polygon*. A regular polygon has all its sides equal, and consequently its angles are also equal, as K, L, M, and N, Figs. 26-29. An irregular polygon has its sides and angles unequal, as H, Fig. 25. Polygons are named according to the number of their sides, or angles, as follows :—

38. A *Pentagon* is a polygon of five sides, as H or K, Figs. 25, 26.

Fig. 25.

Fig. 26.

Fig. 27.



39. A *Hexagon* is a polygon of six sides, as L, Fig. 27.

40. A *Heptagon* has seven sides, as M, Fig. 28.

41. An *Octagon* has eight sides, as N, Fig. 29.

Fig. 28.

Fig. 29.

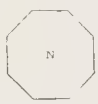
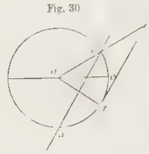


Fig. 30



An *Enneagon* has nine, a *Decagon* ten, an *Undecagon* eleven, and a *Dodecagon* twelve sides. Figures having more than twelve sides are generally designated *Polygons*, or many-angled figures.

42. A *Circle* is a plane figure, bounded by one uniformly curved line, $b\,c\,d$ (Fig. 30), called the circumference, every part of which is equally distant from a point within it, called the centre, as a.

43. The *Radius* of a circle is a straight line drawn from the centre to the circumference: hence all the radii (plural of radius) of the same circle are equal, as $b\,a$, $c\,a$, $e\,a$, $f\,a$, in Fig. 30.

44. The *Diameter* of a circle is a straight line drawn through the centre, and terminated on each side by the circumference; consequently the diameter is exactly twice the length of the radius; and hence the radius is sometimes called the semi-diameter. (See $b\,a\,e$, Fig. 30.)

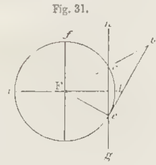
45. The *Chord* or *Subtens* of an arc is any straight line drawn from one point in the circumference of a circle to another, joining the extremities of the arc, and dividing the circle either into two equal, or two unequal parts. If into equal parts, the chord is also the diameter, and the space included between the arc and the diameter, on either side of it, is called a semicircle, as $b\,a\,e$ in Fig. 30. If the parts cut off by the chord are unequal, each of them is called a *segment* of the circle. The same chord is therefore common to two arcs and two segments; but, unless when stated otherwise, it is always understood that the lesser arc or segment is spoken of, as in Fig. 30, the chord $c\,d$ is the chord of the arc $c\,e\,d$.

If a straight line be drawn from the centre of a circle to meet the chord of an arc perpendicularly, as $a\,f$ in Fig. 30, it will divide the chord into two equal parts, and if the straight line be produced to meet the arc, it will also divide the arc into two equal parts, as $c\,f$, $f\,d$.

Each half of the chord is called the sine of the half-arc to which it is opposite; and the line drawn from the centre to meet the chord perpendicularly, is called the co-sine of the half-arc. Consequently, the radius, the sine, and co-sine of an arc form a right angle.

46. Any line which cuts the circumference in two points, or a chord lengthened out so as to extend beyond the boundaries of the circle, such as $g\,h$ in Fig. 31, is sometimes called a *Secant*. But, in trigonometry, the secant is a line drawn from the centre through one extremity of the arc, so as to meet the tangent which is drawn from the other extremity at right angles to the radius. Thus, F $c\,b$ is the secant of the arc $c\,e$, or the angle c F e, in Fig. 31.

Fig. 31.



47. A *Tangent* is any straight line which touches the circumference of a circle in one point, which is called the point of contact, as in the tangent line $e\,b$, Fig. 31.

48. A *Sector* is the space included between any two radii, and that portion of the circumference comprised between them: $c\,e$ F is a sector of the circle $a\,f\,c\,e$, Fig. 31.

49. A *Quadrant*, or quarter of a circle, is a sector bounded by two radii, forming a right angle at the centre, and having one-fourth part of the circumference for its arc, as F $f\,d$, Fig. 31.

50. An *Arc*, or *Arch*, is any portion of the circumference of a circle, as $c\,d\,e$, Fig. 31.

It may not be improper to remark here that the terms circle and circumference are frequently misapplied. Thus we say, describe a circle from a given point, &c., instead of saying, describe the circumference of a circle—the circumference being the curved line thus described, everywhere equally distant from a point within it, called the centre; whereas the circle is properly the superficial space included within that circumference.

51. *Concentric Circles* are circles within circles, described from the same centre; consequently, their circumferences are parallel to one another, as Fig. 32.

52. *Eccentric Circles* are those which are not described from the same centre: any point which is not the centre of a circle is also eccentric in reference to the circumference of that circle. Eccentric circles may also be tangent circles, that is, such as come in contact in one point only, as Fig. 33.

Fig. 32.

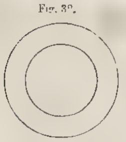


Fig. 33.

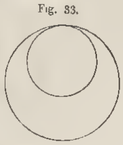
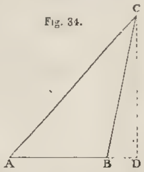


Fig. 34.



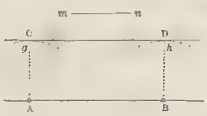
53. *Altitude.* The height of a triangle, or any other figure, is called its *altitude.* To measure the altitude, let fall a straight line from the vertex, or highest point in the figure, perpendicular to the base or opposite side; or to the base produced or continued, as at B D, Fig. 34, should the form of the figure require its extension. Thus C D is the altitude of the triangle A B C.

CONSTRUCTION OF ANGLES, RECTILINEAL FIGURES, &c.

PROBLEM I.—*To draw a straight line parallel to a given straight line at any given distance.*

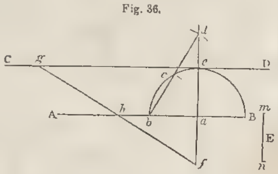
Let A B (Fig. 35) be the given straight line, and let the line $m\,n$ represent the distance required between the parallels. In AB take any two points A and B, and from these points as centres, with a radius equal to the line $m\,n$, describe the arcs g and h; draw the line C D so as to touch these arcs; that is, so as to form their common tangent; and C D will be parallel to A B, as required.

Fig. 35.



Note.—This method of drawing parallels, however current in books on practical geometry, is, to say the least, objectionable, inasmuch as the learner has not been previously informed how to draw tangents to circles or arcs of circles. This objection might be obviated in the following manner: Let A B (Fig. 36) be the given straight line, and the line $m\ n$ the given distance at which the parallel to A B is to be drawn. From B set off B $a = m\,n$, and from a as a centre, with the radius $m\,n$, describe the semicircle B $e\,b$. Again, from b with $m\,n$ or $b\,a$ in the compasses, set off the arc $b\,c$, and having joined these points, produce $b\,c$ till the line $c\,d$ be equal to $b\,c$; join $d\,a$, cutting the circumference in e, and produce $d\,a$ till $a\,f$ be equal to $a\,e$; then draw $f\,g$ at any angle to $d\,f$, cutting A B in h, and make $h\,g = f\,h$. Lastly, through the points e and g draw the straight line C D: it will be parallel to A B, as required.

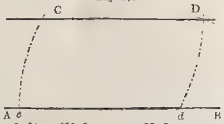
Fig. 36.



PROBLEM II.—*Through a given point* C, *to draw a straight line parallel to a given straight line* A B.

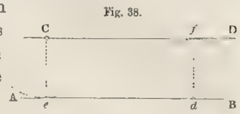
In A B (Fig. 37) take any point d, and from d as a centre with the radius d C, describe an arc C e, cutting A B in e, and from C as a centre, with the same radius, describe the arc d D, make it equal to C e, join C D, and it will be parallel to A B.

Fig. 37.



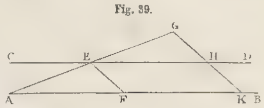
Another Method.—Let A B (Fig. 38) be the given line, and C the given point, as before, through which a parallel is required. From C, with a radius sufficient to reach the nearest part of A B, describe an arc, so that A B may form its tangent, as at e; then from any point d in A B, with the radius C e, describe the arc f: through C draw C D, touching this arc: the line C D is the parallel required.

Fig. 38.



This (II.) problem may be solved without having recourse to arcs, thus:—Let A B (Fig. 39) be the given line, and E the point through which the parallel to A B is required to be drawn. In A B take any point F; join E F, join also A E, and produce it till E G be equal to A E. Likewise make F K = A F, join G K, and make G H or K H = E F; then, through the points E and H, draw the line C D: it will be parallel to the given line A B.

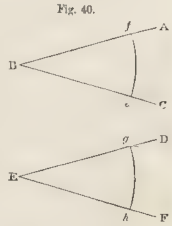
Fig. 39.



PROBLEM III.—*To make an angle equal to a given rectilineal angle.*

From a given point E (Fig. 40), upon the straight line E F, to make an angle equal to the given angle A B C. From the angular point B, with any radius, describe the arc $e\,f$, cutting B C and B A in the points e and f. From the point E on E F with the same radius, describe the arc $h\,g$, and make it equal to the arc $e\,f$; then from E, through g, draw the line E D: the angle D E F will be equal to the angle A B C.

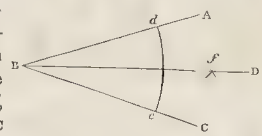
Fig. 40.



PROBLEM IV.—*To bisect a given angle.*

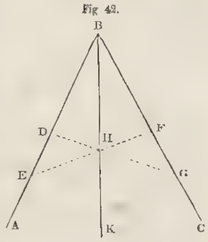
Let A B C (Fig. 41) be the given angle. From the angular point B, with any radius, describe an arc cutting B A and B C in the points d and e; also, from the points d and e as centres, with any radius greater than half the distance between them, describe arcs cutting each other in f; through the point of intersection f, draw B f D: the angle A B C is bisected by the straight line B D; that is, it is divided into two equal angles, A B D and C B D.

Fig. 41.



Or thus.—Let A B C (Fig. 42) be the given angle, as before. In A B take any two points D and E. On B C set off B F equal to B D, and B G equal to B E; join E F and D G, intersecting each other in H; join also B H, and produce it to any point K: the angle A B C is bisected by the line B K.

Fig. 42.

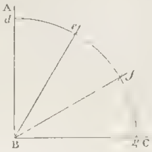


PROBLEM V.—*To trisect or divide a right angle into three equal angles.*

Let A B C (Fig. 43) be the given right angle. From the angular point B, with any radius, describe an arc cutting B A and B C in the points d and g; from the points d and g, with the radius B d or B g, describe arcs cutting the arc

$d\,g$ in e and f: join B e and B f: these lines will trisect the angle A B C, or divide it into three equal angles.

Fig. 43.

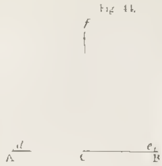


Note.—The trisection of an angle can be effected by means of elementary geometry only in a very few cases; such, for instance, as those where the arc which measures the proposed angle is a whole circle, or a half, a fourth, or a fifth part of the circumference. Any angle of a pentagon is trisected by diagonals, drawn to its opposite angles.

TO ERECT OR LET FALL PERPENDICULAR LINES.

PROBLEM VI.—*From a given point* C, *in a given straight line* A B, *to erect a perpendicular.*

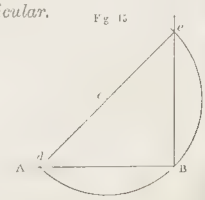
Fig. 44.



From the point C (Fig. 44), with any radius less than C A or C B, describe arcs cutting the given line A B in d and e; from these points as centres, with a radius greater than C d or C e, describe arcs intersecting each other in f: join C f, and this line will be the perpendicular required.

PROBLEM VII.—*From the point* B, *at the extremity of the line* A B, *to erect a perpendicular.*

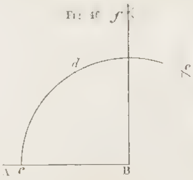
Fig. 45.



Above the given line A B (Fig. 45), take any point c, and with the radius or distance c B, describe the portion of the circle d B e; join $d\,c$, and extend it to meet the opposite circumference in e: draw the line Be, which will be the perpendicular required.

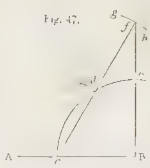
Another Method.—From the point B (Fig. 46), with any radius, describe the arc $c\,d\,e$; and from the point c, where the arc meets the line A B, with the radius B c, cut the arc in d; and from d, with the same radius, cut it also in e. Again, from the points d and e, with equal radii — greater than half the distance from d to e—describe arcs intersecting each other in f: a line joining B f will be the perpendicular required.

Fig. 46.



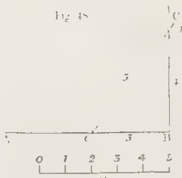
Or thus.—In A B (Fig. 47) take any point c; from B as a centre, with the radius B c, describe the portion of a circle $c\,e$; again, from c, with the same radius, draw an arc cutting the former in d; also from d as a centre, with the same radius, describe the arc $g\,h$; join $c\,d$, and extend it to meet $g\,h$ in f: a line drawn from f, the point of intersection, to B, will be the perpendicular to A B as before.

Fig. 47.



Another Method.—To draw a right angle or erect a perpendicular by means of any scale of equal parts, or standard measure of inches, feet, yards, &c., by setting off distances in proportion to the numbers 3, 4, and 5, or 6, 8, and 10, or any numbers whose squares correspond to the sides and hypotenuse of a right-angled triangle.

Fig. 48.



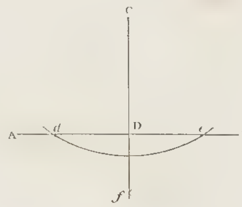
From any scale of equal parts, as that represented by the line D (Fig. 48), which contains 5; set off from B, on the line A B, the distance B e, equal to 3 of these parts; then from B, with a radius equal to 4 of the same parts, describe the arc $a\,b$; also from e as a centre, with a radius equal to 5 parts, describe another arc intersecting the former in C; lastly join B C; the line B C will be perpendicular to A B.

Note.—This mode of drawing right angles is more troublesome upon paper than the methods previously given; but in laying out grounds or foundations of buildings it is often useful, since only with a measuring rod, line, or chain, perpendiculars may be set out very accurately. The method is demonstrated thus:—The square of the hypotenuse, or longest side of a right-angled triangle, being equal to the sum of the squares of the other two sides, the same property must always be inherent in any three numbers, of which the squares of the two lesser numbers, added together, are equal to the square of the greater. For example, take the numbers 3, 4, and 5; the square of 3 is 9, and the square of 4 is 16; 16 and 9 added together make 25, which is 5 times 5, or the square of the greater number. Although these numbers, or any multiple of them, such as 6, 8, 10, or 12, 16, 20, &c., are the most simple, and most easily retained in the memory, yet there are other numbers, very different in proportion, which can be made to serve the same purpose. Let n denote any number; then n^2+1, n^2-1, and $2n$, will represent the hypotenuse, base, and perpendicular of a right-angled triangle. Suppose $n=6$, then $n^2+1=37$, $n^2-1=35$, and $2n=12$: hence, 37, 35, and 12, are the sides of a right-angled triangle.

PROBLEM VIII.—*From a given point* C, *to let fall a perpendicular to a given straight line* A B.

From the point C (Fig. 49), with any radius greater than its distance from the line A B, describe an arc cutting A B in the points d and e; also, from d and e, with equal radii—greater than half the distance between these points—describe arcs on the opposite side of A B, intersecting each other at f; join f C, cutting A B in D: C D will be a perpendicular let fall upon A B, as required.

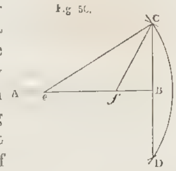
Fig. 49.



Another Method.—When the given point whence the perpendicular is to be drawn is nearly opposite the end of the line.

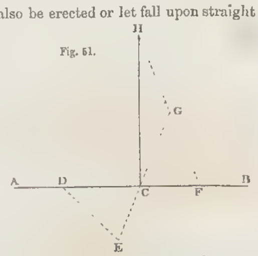
Let C be the given point (Fig. 50), and A B the given line, as formerly. In A B, take any convenient point e, and from it, with a radius equal to e C, describe an arc C D: between B and e, take any other point f; and from f, with $f\,c$ as a radius, describe arcs cutting the former arc in C and D: a straight line drawn through these points of intersection will be perpendicular to the given line A B.

Fig. 50.



Note.—Perpendiculars may also be erected or let fall upon straight lines, without having recourse to the arcs of circles, by means of straight lines only. This may be shown as follows:—Let A B (Fig. 51) be a given straight line, and C a given point in it; it is required to draw a line from the point C at right angles to A B. Between C and A take any point D; draw D E at any angle to D B, and equal to D C; join E C, and produce it to G, making C G = C D. On C B set off C F equal to C E; join F G, and produce it till G H be equal

Fig. 51.



to G F or G C; draw C H: it will be perpendicular to A B.—Again, let A B (Fig. 52) be the given straight line, and C the given point from which it is proposed to let fall a perpendicular upon A B. In A B, take any point D, and join C D; then towards A set off D E = C D; also towards B set off D F = D E or D C; join E C and C F. Again, produce E C till E G be equal to E F, and from E F cut off E H = E C; join G H, and extend it on the other side of A B till H K be equal to G H. Then join K E, and cut off K L = C G; join C L, cutting A B in M: C M is the perpendicular let fall upon A B.

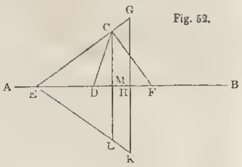


Fig. 52.

PROBLEM IX.—*To bisect a given straight line.*

Let A B (Fig. 53) be the given straight line. From the extreme points A and B as centres, with any equal radii greater than half the length of A B, describe arcs cutting each other in C and D: a straight line drawn through the points of intersection C and D, will bisect the line A B in *e*.

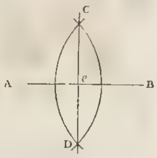


Fig. 53.

PROBLEM X.—*To divide a given straight line into any number of equal parts.*

Let A B (Fig. 54) be the given line to be divided into five equal parts. From the point A draw the straight line A C, forming any angle with A B. On the line A C, with any convenient opening of the compasses, set off five equal parts towards C; join the extreme points C B; through the remaining points, 1, 2, 3, and 4, draw lines parallel to B C, cutting A B in the corresponding points, 1, 2, 3, and 4: A B will be divided into five equal parts, as required.

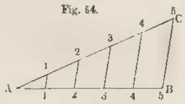


Fig. 54.

Another Method.—Let A B (Fig. 55) be the given straight line, which we shall suppose, in this instance, is to be divided into four equal parts. Draw the straight line C D of any convenient length, and from C set off four equal parts. Then from C, with a radius equal to the distance from C to the last division, or number 4, on the line C D, describe an arc; and from the point marked 4, with the same radius, describe another arc cutting the former in G. From the point of intersection G, draw G C, G 1, G 2, G 3, and G 4. Again, from G, with a radius equal to the given line A B, describe an arc cutting G C and G 4 in the points E and F; join these points: the line E F will be equal to the given line A B, and it will also be divided into four equal parts by the lines G 1, G 2, and G 3.

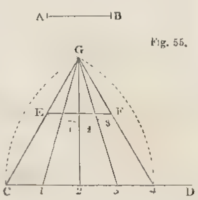


Fig. 55.

A line may be divided into any number of equal parts very simply, by means of a ruler, or scale of equal parts, without the help either of arcs or compasses. Thus:—

Let A B (Fig. 56) be the given straight line, and let it be required to divide it into any number—say five equal parts. Draw A C, making any angle with A B; and from A towards C, set off any five equal parts; join 5 B, and produce it indefinitely towards D. Again, from 5, on the line 5 D, with the same or any other scale, set off five equal parts, as before, marked I, II, III, IV, V; then join A V, 1 IV, 2 III, 3 II, and 4 I. From A set off A *a* = 4 I, A *b* = 3 II, A *c* = 2 III, and A *d* = 1 IV. Join also *a* 1, *b* 2, *c* 3, and *d* 4, cutting A B in 1′, 2′, 3′, 4′: A B is divided into five equal parts by these lines.

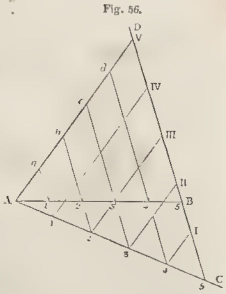


Fig. 56.

The bisection of a line by this method is exceedingly simple, as is shown by Fig 57.

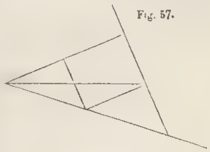


Fig. 57.

By either of the two preceding methods, scales or drawings may be reduced or enlarged proportionably, so that each part of a given scale or drawing shall bear the same proportion to similar parts of another scale or drawing of a different size.

A fourth proportional to three given lines, may be found, in like manner, by this problem. Assume A E, E B, and A D (Fig. 58), to be three given lines, the two first, A E, E B, being placed in the same straight line, and A D, the third line, making any angle with A B: having joined D E, through B draw B C, parallel to D E, meeting A D produced in C; D C is a fourth proportional to these three lines. For, by the first method of this problem, D C and E B are similar portions of the lines A C and A B: wherefore the part D C has the same ratio to the remaining part A D that the part E B of the line A B has to the remainder A E.

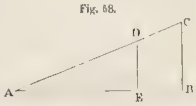


Fig. 58.

As regards scales and drawings. Let A B (Fig. 59), represent the length of one scale or drawing, divided into the given parts A *d*, *d e*, *e f*, *f g*, *g h*, and *h* B; and D E the length of another scale or drawing required to be divided into similar parts. From the point B draw a line B C = D E, and forming any angle with A B; join A C, and through the points *d*, *e*, *f*, *g*, and *h*, draw *d k*, *e l*, *f m*, *g n*, *h o*, parallel to A C; and the parts C *k*, *k l*, *l m*, &c., will be to each other, or to the whole line B C, as the lines A *d*, *d e*, *e f*, &c., are to each other, or to the given line or scale A B. By the second method, as will be evident from the figure, similar divisions can be obtained in lines of any given length.

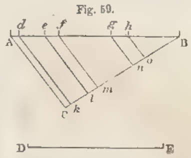


Fig. 59.

PROBLEM XI.—*To describe an equilateral triangle upon a given straight line.*

Let A B (Fig. 60) be the given straight line. From the points A and B, with a radius equal to A B, describe arcs intersecting each other in the point C. Join C A and C B, and A B C will be the equilateral triangle required.

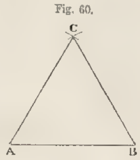
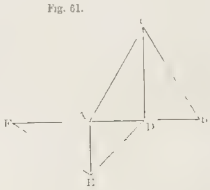


Fig. 60.

Note.—An eminent mathematician has made the following observation regarding this problem:—"It is remarkable that it is not perhaps possible to resolve, without employing the arc of a circle, the very simple problem, and one of the first in the elements of geometry, viz., to describe an equilateral triangle." "We have often attempted it," continues the same author, "but without success, while trying how far we could proceed in geometry by means of straight lines only." He did right to put in *perhaps*, as the thing happens to be possible after all, but it shows by what trifles the greatest men will sometimes be baffled. We submit the following

method as remarkably simple and easy:—Let A B (Fig. 61) be the given straight line. It is required to describe an equilateral triangle upon it without making use of the compasses or arcs of a circle. Bisect A B in D (as shown in a former note), draw A E perpendicular and equal to A D; join D E, and extend D A to F, making A F = D E; join also E F; then from D erect the perpendicular D C = E F, and join A C and C B: A B C will be an equilateral triangle.

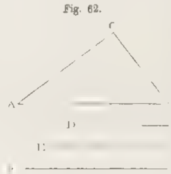
Fig. 61.



It is easy to see that AC^2 must be $4AD^2$; but $AC^2 = AD^2 + CD^2$ (47 Prop. Euclid), and $CD^2 = EF^2 = FA^2 + AE^2 = AE^2 + DE^2$; but $DE^2 = AD^2 + AE^2 = 2AD^2 \therefore CD^2 = 3AD^2$, and $AC^2 = AB^2 = 4AD^2$. Q. E. D.

PROBLEM XII.—*To construct a triangle whose sides shall be equal to three given lines.*

Fig. 62.



Draw A B (Fig. 62) equal to the given line F. From A as a centre, with a radius equal to the line E, describe an arc; then from B as a centre, with a radius equal to the line D, describe another arc intersecting the former in C; join C A and C B, and A B C will be the triangle required.

PROBLEM XIII.—*To find the length of the hypotenuse, or longest side of a right-angled triangle, whose other two sides are equal to two given lines* D *and* E.

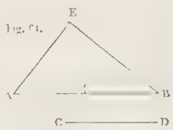
Fig. 63.

Draw A B (Fig. 63) equal to the line E, and from the point B draw B C perpendicular and equal to the line D. Join A C, which will be the hypotenuse required.

PROBLEM XIV.—*The hypotenuse* A B, *and one side* C D, *of a right-angled triangle being given, to find the other side.*

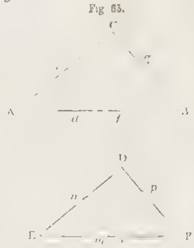
Bisect the hypotenuse A B in *e* (Fig. 64), and from *e* as a centre, with a radius equal to *e* B or *e* A, describe an arc; also from A as a centre, with a radius equal to the given line C D, describe another arc, intersecting the former in E; join E A and E B; and E B will be the side required of the right-angled triangle A B E.

Fig. 64.



PROBLEM XV.—*On a given line* E F, *to construct a triangle similar to a given triangle* A B C.

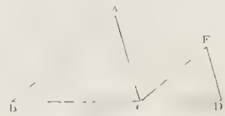
Fig. 65.



From the angular point A of the given triangle (Fig. 65), with any radius, describe the arc *de*, cutting A B and A C in the points *d* and *e*. Also, from E, the one extremity of the given line E F, with the same radius, describe the arc *m n*: take the arc *d e* in the compasses, and apply it from *m* to *n*, so as to make it equal to *d e*. Again, from the angular point B, with the same or any other radius, describe the arc *f g*: likewise, from F, the other extremity of E F, with the same radius, draw the arc *o p*, making it equal to *f g*. Through the points *n* and *p* draw lines from E and F, meeting in D: the triangle E F D will be similar to the triangle A B C, as required.

Another Method.—Let A B C be the given triangle (Fig. 66). Produce one of its sides B C till the extension C D be equal to the corresponding side of the proposed triangle. Through the point C draw a line C E parallel to B A; also, through the extreme point D, draw D E parallel to C A, meeting C E in E, and the triangle E C D will be similar to the triangle A B C.

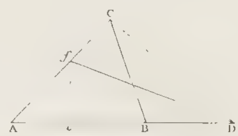
Fig. 66.



Note.—This example illustrates some of the most important properties of triangles; as, for instance, that the alternate angles formed by a straight line, cutting two or more parallel lines, are equal; likewise, that the angles formed by one line falling upon another, will either be two right angles, or will be together equal to two right angles; wherefore, the angles A C B and A C D are together equal to two right angles.

PROBLEM XVI.—*To change a given triangle into another of equal area, having either its base or altitude greater or less than the base or altitude of the given triangle.*

Fig. 67.



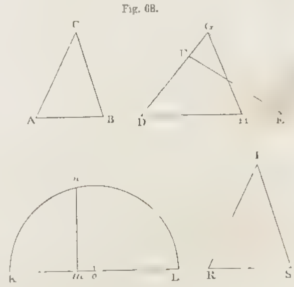
Let A B C be the given triangle (Fig. 67), and *e f* the altitude of the proposed triangle. From the given height or altitude at *f*, draw the dotted line *f* B; and through the point C, draw another dotted line, parallel to *f* B, and meeting the base line produced in D. Join *f* D; then the triangle A D *f* will be equal in area to the given triangle A B C. *Or conversely:* let A D *f* be the given triangle, and let C, or any point in A *f* produced, be the vertex or altitude of the proposed triangle: draw a dotted line from C to D, as before; also, through *f*, draw *f* B, parallel to C D; join C B, which will complete the required triangle A B C.

It must be evident from Fig. 67, that the same rule is applicable to any given difference, either in the base or altitude of triangles of equal area.

PROBLEM XVII.—*Two dissimilar triangles being given, to construct a third, which will be similar to the one, and equal in area to the other.*

Let A B C (Fig. 68) be one of the given triangles, to which the proposed triangle is to be similar, and D E F the other given triangle to which it is required to be equal in area. By Problem XVI., change the triangle D E F into another, D H G, having its altitude equal to that of the triangle A B C. Take any indefinite straight line K L, limited at the one extremity K; and from K set off K *m* equal to A B, and *m* L equal to D H: bisect the whole line K L in *o*; then from *o* as a centre, with a radius equal to *o* K or *o* L describe the semicircle K *n* L: also, from the point *m*, draw the line *m n* perpendicular to K L, meeting the circumference in *n*: *m n* is a mean proportional between K *m* and *m* L, or their equals A B and D H. Lastly, draw the straight line

Fig. 68.



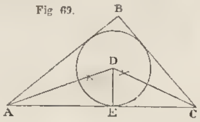
R S equal to $m\,n$, and upon this line (by Problem XV.) construct a triangle R S T similar to A B C, and it will likewise be equal in area to the triangle D H G, or its equal D E F, as required.

Note.—The truth of this method may be proved shortly thus:—Put A B $=a$, D H $=b$, and the perpendicular height of the triangles of which A B and D H are the bases, equal to d. Also let the base of the triangle sought be represented by x, and its height by y. Then by similar triangles $a : x :: d : y$, and $y = \frac{d\,x}{a}$. Again, because the triangle sought must be equal to D G H, $xy = d\,b$, and $y = \frac{d\,b}{x}$. ∴ $\frac{d\,x}{a} = \frac{d\,b}{x}$ or $d\,x^2 = a\,d\,b$ and $x^2 = a\,b$, or $x =$ R S, is a mean proportional between a and b, that is, between A B and D H.

PROBLEM XVIII.—*To inscribe a circle in a given triangle.*

Let A B C (Fig. 69) be the given triangle. Bisect any two of its angles, as those at A and C, by the straight lines A D and C D. From the point D, where the bisecting lines meet, let fall the perpendicular D E upon the line A C; then from D as a centre, with the radius D E, describe a circle. This circle will be inscribed in the triangle A B C, as required.

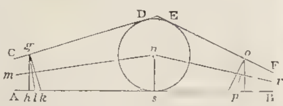
Fig. 69.



PROBLEM XIX.—*To inscribe a circle within three given oblique lines, which, if produced, would form a triangle, but whose angular points are supposed to be inaccessible.*

From any point g in the line C D (Fig. 70), let fall $g\,h$ perpendicular to A B; and from the same point g erect a perpendicular to C D, meeting A B in k; bisect the angle $k\,g\,h$ by the line $g\,l$; bisect also the line $g\,l$ by the perpendicular line $m\,n$. In like manner, find the line $o\,p$; bisect it also, and through the point of bisection draw the perpendicular line $r\,n$, meeting $m\,n$ in the point n. Lastly, from n, the point of intersection, let fall upon A B the perpendicular $n\,s$: $n\,s$ will be the radius of the required circle.

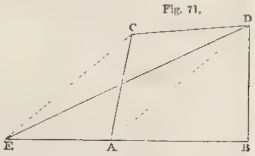
Fig. 70.



PROBLEM XX.—*To construct a triangle equal in magnitude or area to a given trapezium.*

Let A B D C (Fig. 71) be the given trapezium. Draw the diagonal A D; then through C draw C E parallel to A D, and meeting the base A B produced in E; join E D, and B D E will be a triangle equal in area to the given trapezium A B D C.

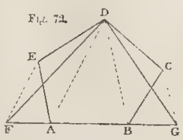
Fig. 71.



PROBLEM XXI.—*To construct a triangle equal in area to a given pentagon.*

Let A B C D E (Fig. 72) be the pentagon to which the triangle is to be equal. Draw (with dotted lines) the diagonals A D and D B; draw also E F parallel to D A, and C G parallel to D B, meeting the base extended both ways in F and G. Join D F and D G, and D F G will be a triangle equal in area to the given pentagon, A B C D E.

Fig. 72.

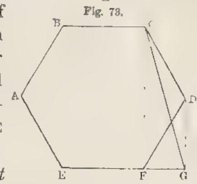


In like manner, any other figure formed by straight lines may be reduced to a triangle. Should the given figure be a polygon of more than five sides, it will be necessary to change it into another of one side less successively, until it be reduced to five sides, by the method employed in the preceding examples.

PROBLEM XXII.—*To reduce a hexagon, or six-sided figure, to a pentagon, or five-sided figure.*

Let A B C D E F (Fig. 73) be the given hexagon. Draw a diagonal between any two of its alternate angles, as C F; then through the intermediate angular point D draw the line D G parallel to C F, meeting the base E F extended in G. Join C G, and A B C G E will be the pentagon required.

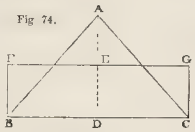
Fig. 73.



PROBLEM XXIII.—*To construct a rectangle, or parallelogram, equal to a given triangle.*

Let A B C (Fig. 74) be the given triangle, and the dotted line A D its altitude or perpendicular height. Bisect A D in E, and through the point E draw F E G parallel to B D C. Again, through B and C, the extremities of the base, draw B F and C G, each parallel to A D, and meeting the line F E G in the points F and G: then B C G F is the rectangle or parallelogram required.

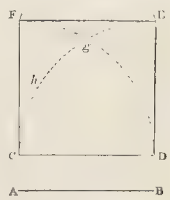
Fig. 74.



PROBLEM XXIV.—*To describe a square, or equilateral rectangle, the sides of which shall be equal to a given straight line.*

Let A B (Fig. 75) be the straight line to which the sides of the square are to be equal. Draw C D equal to A B, and from C and D as centres, with a radius equal to C D, describe the arcs D F and C E, intersecting each other in g: bisect the arc C g in h: from g as a centre, with radius $g\,h$, draw arcs cutting C E and D F in E and F. Join D E, E F, and F C: C D E F is the square required.

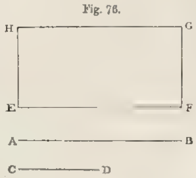
Fig. 75.



PROBLEM XXV.—*To construct a rectangle whose sides shall be equal to two given lines.*

Let A B and C D (Fig. 76) be the given lines. Draw the straight line E F equal to A B, and from E draw E H perpendicular to E F, and equal to C D; then from H and F as centres, with radii equal to A B and C D, describe arcs intersecting in G. Join F G and G H, and E F G H will be the parallelogram or rectangle required. Parallelograms of any form may be drawn in a similar manner.

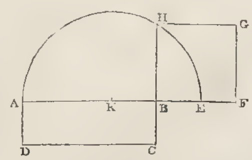
Fig. 76.



PROBLEM XXVI.—*To describe a square equal to a given rectangle.*

Let A B C D (Fig. 77) be the given rectangle. Produce A B, one side of the rectangle, to E, and make B E equal to B C. Bisect A E in K, and from K as a centre, with the radius K A or K E, describe the semicircle A H E. Produce C B to meet

Fig. 77.

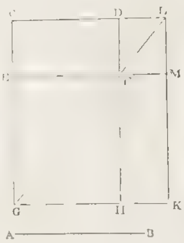


the circumference in H; extend B E to F, and make B F equal to B H; then complete the square B F G H, and it will be equal to the given rectangle.

Thus, by means of this, and Problem XXIII., a triangle can be successively changed, first into a rectangle, then from a rectangle into a square, in such a manner that all the three figures shall still be equal in area.

PROBLEM XXVII.—*To describe a rectangle or parallelogram having one of its sides equal to a given line, and its area equal to that of a given rectangle.*

Fig. 78.

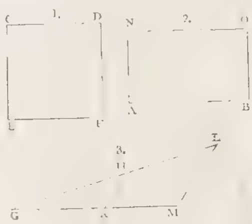


Let A B (Fig. 78) be the given line, and C D E F the given rectangle. Produce C E to G, making E G equal to A B; from G draw G K parallel to E F, and meeting D F produced in H. Draw the diagonal G F, extending it to meet C D produced in L; also draw L K parallel to D H, and produce E F till it meet L K in M; then F M K H is the rectangle required.

Note.—Equal and similar rhomboids or parallelograms of any dimensions may be drawn after the same manner, seeing the complements of the parallelograms which are described on or about the diagonal of any parallelogram, are always equal to each other; while the parallelograms themselves are always similar to each other, and to the original parallelogram about the diagonal of which they are constructed. Thus, in the parallelogram C G K L the complements C E F D and F M K H are always equal, while the parallelograms E F H G and D F M L about the diagonal G L, are always similar to each other, and to the whole parallelogram C G K L.

Another Method.—Let C D E F (Fig. 79, No. 1) be the given rectangle, and A B (No. 2) a side of the proposed rectangle. Find a fourth proportional to the three following straight lines, viz., A B the given line, C D and D F sides of the given rectangle. Thus, from any point G (No. 3), draw two diverging lines G H and G K, equal to A B and C D, making any angle at the point G. Join K H, and produce G H till H L be equal to D F; then, through L, draw L M parallel to H K: K M will be a fourth proportional to A B, C D, and D F. Upon the given line A B describe the parallelogram A B O N, having each of its sides A N and B O equal to K M, and it will be the rectangle required.

Fig. 79

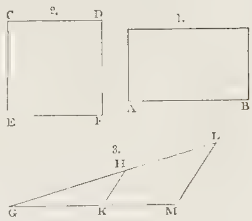


When two sides of one rectangle are reciprocally proportional to two sides of another, the rectangles must necessarily be equal; because, when four straight lines are geometrically proportional, the product of the first and fourth, or of the extremes, is always equal to the product of the second and third, or of the mean proportionals.

PROBLEM XXVIII.—*Upon a given straight line to construct a rectangle equal to a given square.*

Let A B (Fig. 80, No. 1) be the given straight line, and C D E F (No. 2) the given square. Draw any two straight lines G H and G K (No. 3), forming any angle at G. Make G H equal to the given line A B, and G K equal to C D, a side of the given square. Produce G H to L, so that H L may be equal to K G; join K H; then draw M L parallel to K H; join also K M, and it will be a third proportional to A B and C D. Lastly, upon A B as a base, describe a rectangle having its altitude equal to K M, and it will be equal in area to the given square, as required.

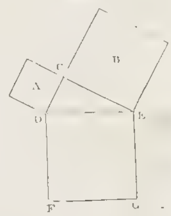
Fig. 80.



PROBLEM XXIX.—*To describe a square equal to two given squares.*

Let A and B (Fig. 81) be the given squares. Place them so that a side of each may form the right angle D C E; join D E, and upon this hypotenuse describe the square D E G F, and it will be equal to the sum of the squares A and B, which are constructed upon the legs of the right-angled triangle D C E. In the same manner, any other rectilineal figure, or even circle, may be found equal to the sum of other two similar figures or circles. Suppose the lines C D and C E to be the diameters of two circles, then D E will be the diameter of a third, equal in area to the other two circles. Or suppose C D and C E to be the like sides of any two similar figures, then D E will be the corresponding side of another similar figure, equal to both the former.

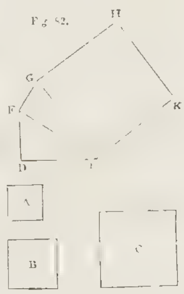
Fig. 81



PROBLEM XXX.—*To describe a square equal to any number of given squares.*

Let it be required to construct a square equal to the three given squares A, B, and C (Fig. 82). Take the line D E, equal to the side of the square C. From the extremity D erect D F perpendicular to D E, and equal to the side of the square B; join E F; then a square described upon this line will be equal to the sum of the two given squares C and B. Again, upon the straight line E F erect the perpendicular F G, equal to the side of the third given square A; and join G E, which will be the side of the square G E H K, equal in area to A, B, and C. Proceed in the same way for any number of given squares.

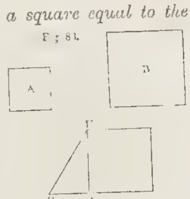
Fig. 82.



PROBLEM XXXI.—*To describe a square equal to the difference of two unequal squares.*

Let A and B (Fig. 83) be the given squares. Describe a right-angled triangle, having its base C D equal to the side of the square A, and its hypotenuse C E equal to the side of the square B; then E D, the third side of the right-angled triangle D E C, is the side of a square, the area of which

Fig. 83.

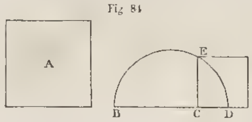


will be equal to the difference of the areas of the two given squares A and B.

PROBLEM XXXII.—*To describe a square which shall be equal to any portion of a given square.*

Let A (Fig. 84, No. 1) be the given square, and let it be required to construct another square, whose area shall be one-third of A. Draw the straight line BC (No. 2) equal to the side of the given square A: produce this line to D, making CD equal to one-third of BC.

Fig. 84.



Upon the whole line BD describe a semicircle, and from C erect CE perpendicular to BD. CE being a mean proportional between the two segments BC and CD of the line BD, will, consequently, be a side of the square required.

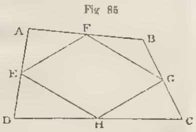
In like manner, a square may be described, having any given ratio to a given square, or which may be any given multiple of another square. The first case of the problem is effected (as has been shown) by making the extension or part added to the given line equal to the required ratio; the second, by making the part produced equal to the required multiple of the given square.

Remark.—Although, for the sake of brevity and simplicity, the four preceding problems have been restricted to the construction of squares, the same methods are equally applicable to all similar rectilineal, curvilineal, or mixilineal plane figures. For circles, as already stated in Problem XXIX., we have only to substitute their diameters for the sides of squares; whereas, in other cases, the lines forming a right-angled triangle can be supposed the homologous, or like sides of the similar figures to which they belong.

PROBLEM XXXIII.—*To inscribe a parallelogram in a given quadrilateral figure.*

Let ABCD (Fig. 85) be the given quadrilateral in which the parallelogram is to be inscribed. Bisect each of the sides in the points E, F, G, and H. Join EF, FG, GH, and HE, and the rectilineal figure EFGH, thus formed, will be the parallelogram required.

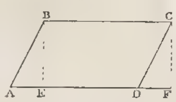
Fig. 85.



PROBLEM XXXIV.—*To describe a rectangle equal to a given rhomboid.*

Let ABCD (Fig. 86) be the given rhomboid or parallelogram to which the rectangle is required to be equal. From each of the angular points B and C, upon the same side, let fall perpendiculars BE and CF upon AD, or upon AD produced to F, and the rectangle BCFE will be equal in area to the given rhomboid ABCD.

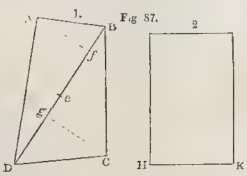
Fig. 86.



PROBLEM XXXV.—*To describe a rectangle equal to a given irregular quadrilateral figure.*

Let ABCD (Fig. 87, No. 1) be the given quadrilateral. Between any two of its opposite angles, as B and D, draw the diagonal BD; then from the other two opposite angles, at A and C, let fall the perpendiculars A*f* and C*g* upon the diagonal BD, or upon BD produced if necessary. Again, bisect BD in *e*, and draw the straight line HK (No. 2) equal to B*e* or D*e*, half the diagonal. Upon the line HK as a base, construct a rectangle, having its height equal to the sum of the perpendiculars A*f* and C*g*: the rectangle thus described will be equal to the given quadrilateral ABCD.

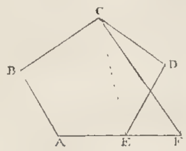
Fig. 87.



PROBLEM XXXVI.—*To describe a quadrilateral figure equal to a given pentagon.*

Let ABCDE (Fig. 88) be the given pentagon. Join any two of its alternate angles, as for instance those at C and E, by the diagonal line CE; then through the intermediate angular point D draw the line DF parallel to CE, meeting AE produced in F: join CF, and the quadrilateral figure ABCF will be equal to the given pentagon ABCDE, as required. Upon the same principle, any rectilineal figure may be reduced into another having one side less, but still equal in area to the original given figure, as has been already illustrated in Problems XX., XXI., and XXII.

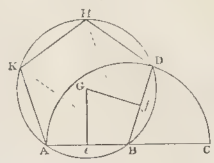
Fig. 88.



PROBLEM XXXVII.—*Upon a given straight line to describe any regular polygon.*

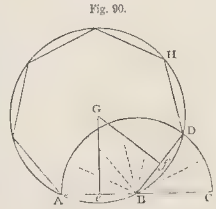
EXAMPLE I. *Upon a given line* AB (Fig. 89) *to describe a regular pentagon.*—Produce AB to C, so that BC may be equal to AB: from B as a centre, with the radius BA or BC, describe the semicircle ADC: divide the semi-circumference ADC into as many equal parts as there are sides in the required polygon, which in the case before us will be five: through the second division from C draw the straight line BD, which will form another side of the figure. Bisect AB at *e* and BD at *f*, and draw *e*G and *f*G perpendiculars to AB and BD; then G, the point of intersection, is the centre of a circle, of which AB and D are points in the circumference. From G, with a radius equal to its distance from any of these points, describe the circumference ABDHK; then by producing the dotted lines from the centre B, through the remaining divisions in the semicircle ADC, so as to meet the circumference of which G is the centre, in H and K, these points will divide the circle ABDHK into the number of parts required, each part being equal to the given side of the pentagon.

Fig. 89.



EXAMPLE II. *Upon a given straight line to describe a regular heptagon.*—Let AB (Fig. 90) be the given straight line. As in the former example, from B, with a radius equal to AB, describe the semicircle ADC, and produce AB to meet it in C. Divide the semi-circumference ADC into seven equal parts—the number of sides in a *heptagon.* Draw BD, as before, through the second division of the semicircle from C: bisect also AB in *e*, and BD in *f*, and draw *e*G and *f*G respectively perpendicular to AB and BD. G, as formerly, is the centre of a circle, whose circumference passes through the points AB and D. Complete the circle ABDH, and it will contain the given side AB seven times, which is the number of sides required.

Fig. 90.



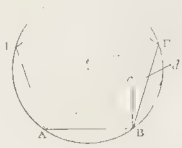
Remark.—From the preceding examples it is evident that polygons of any number of sides may be constructed upon the same principles, because the circumferences of all circles, when divided into the same number of equal parts, produce equal angles; and, consequently, by dividing the semi-circumference of any given circle into the number of parts required, two of these parts will form an angle, which will be subtended by its corresponding part of the whole circumference. And as all regular polygons can be inscribed in a circle, it must necessarily follow, that if a circle be described through three given angles of that polygon, it will contain the number of sides or angles required.

The above is a general rule, by which all regular polygons may be described upon a given straight line; but there are other methods by which many of them may be more expeditiously constructed, as shown in the following examples:—

PROBLEM XXXVIII.—*Upon a given straight line to describe a regular pentagon.*

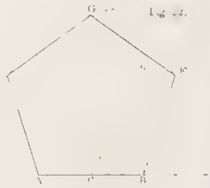
Let A B (Fig. 91) be the given straight line; from its extremity B erect B *c* perpendicular to A B, and equal to its half. Join A *c*, and produce it till *c d* be equal to B *c*, or half the given line A B. From A and B as centres, with a radius equal to B *d*, describe arcs intersecting each other in *e*, which will be the centre of the circumscribing circle A B F G H. The side A B applied successively to this circumference, will give the angular points of the pentagon; and these being connected by straight lines, will complete the figure.

Fig. 91.



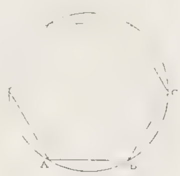
Another Method.—Let A B (Fig. 92) be the given line, upon which the pentagon is to be described. Erect B *d* perpendicular and equal to A B. Bisect A B in *c*, and join *c d*: produce A B, making *c e* equal to *c d*. Then from A and B as centres, with the radius A *e*, describe the arcs G H and G F, intersecting each other in G. Again, from the same points A and B, with the radius A B, describe arcs intersecting the former in H and F. Join B F, F G, G H, and H A, and the rectilineal figure A B F G H will be a regular pentagon, having A B as one of its sides, as required.

Fig. 92.



PROBLEM XXXIX.—*Upon a given straight line to describe a regular hexagon.*

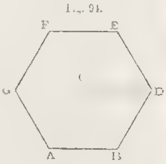
Fig. 93.



Let A B (Fig. 93) be the given straight line. From the extremities A and B as centres, with the radius A B, describe arcs cutting each other in *g*. Again from *g*, the point of intersection, with the same radius, describe the circle A B C, which will contain the given side A B six times when applied to its circumference, and will be the hexagon required.

Another Method.—Upon the given line A B (Fig. 94) describe (Problem XI.) the equilateral triangle A B C. Extend the sides A C and B C to E and F, making CE and CF each equal to a side of the triangle. Bisect the angles A C F and B C E by the straight line G C D, drawn through the common vertex C, and make C D and C G each equal to C E or C F. Join B D, D E, E F, F G, and G A; then A B D E F G is a regular hexagon, described upon A B, as required.

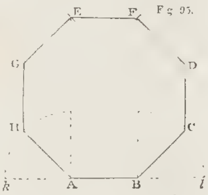
Fig. 94.



PROBLEM XL.—*To describe a regular octagon upon a given straight line.*

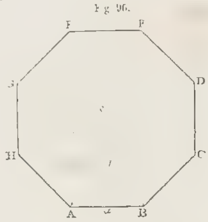
Let AB (Fig. 95) be the given line. From the extremities A and B erect the perpendiculars A E and B F: extend the given line both ways to *k* and *l*, forming external right angles with the lines A E and B F. Bisect these external right angles, making each of the bisecting lines A H and B C equal to the given line A B. Draw H G and C D parallel to A E or B F, and each equal in length to A B. From G draw G E parallel to B C, and intersecting A E in E, and from D draw D F parallel to A H, intersecting B F in F. Join E F, and A B C D F E G H is the octagon required. Or from D and G as centres, with the given line A B as radius, describe arcs cutting the perpendiculars A E and BF in E and F, and join G E, E F, F D, to complete the octagon.

Fig. 95.



Otherwise, thus.—Let A B (Fig. 96) be the given straight line on which the octagon is to be described. Bisect it in *a*, and draw the perpendicular *a b* equal to A *a* or B *a*. Join A *b*, and produce *a b* to *c*, making *b c* equal to A *b*: join also A *c* and B *c*, extending them so as to make *c* E and *c* F each equal to A *c* or B *c*. Through *c* draw G *c* G at right angles to A E. Again, through the same point *c*, draw D H at right angles to B F, making each of the lines *c* C, *c* D, *c* G, and *c* H equal to A *c* or *c* B, and consequently equal to one another. Lastly, join B C, C D, D E, E F, F G, G H, H A: A B C D E F G H will be a regular octagon, described upon A B, as required.

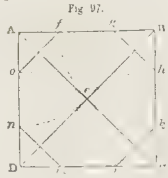
Fig. 96.



PROBLEM XLI.—*In a given square to inscribe a given octagon.*

Let A B C D (Fig. 97) be the given square. Draw the diagonals A C and B D, intersecting each other in *e*; then from the angular points A B C and D as centres, with a radius equal to half the diagonal, viz., A *e* or C *e*, describe arcs cutting the sides of the square in the points *f*, *g*, *h*, *k*, *l*, *m*, *n*, *o*, and the straight lines *o f*, *g h*, *k l*, and *m n*, joining these points will complete the octagon, and be inscribed in the square A B C D, as required.

Fig. 97.

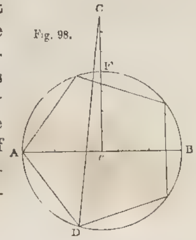


PROBLEM XLII.—*To inscribe any regular polygon in a given circle.*

Let A B D (Fig. 98) be the given circle, in which it is required to inscribe a regular *pentagon*. Draw the diameter A B of the given circle, and divide it into the same number of equal parts as there are sides in the required polygon, viz., five. Bisect A B in *e*, and erect *e* C perpendicular to A B, cutting the circumference in F; and make F C, the part without the circle, equal to three-fourths of the radius A *e* or *e* B. From C, the extremity of the extended radius

draw the straight line C D through the second division from A of the diameter A B, producing it to meet the opposite circumference at D. Join D A; then the line or distance between the point D thus found, and the adjacent extremity A of the diameter A B, will be a side of the required polygon; and if successively applied to the circumference A D B will form the pentagon, as proposed.

Fig. 98.



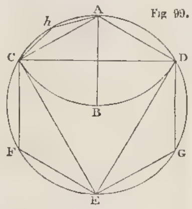
Again, by the second method, when the polygon to be inscribed is a hexagon, the diameter is divided into six equal parts; and if lines be drawn from the extremity of a perpendicular, whose position and height is determined as before, so as to pass through the first division on each side of the centre, and continued to cut the opposite circumference, the chord which is formed by joining the points of intersection will subtend twice 30, or 60 degrees, which is a sixth part of the circumference, and therefore a side of the hexagon.

These are general rules for the inscription of polygons; but there are other methods of inscribing plane figures in circles, as will be shown in the succeeding examples.

PROBLEM XLIII.—*In a given circle to describe an equilateral triangle, a hexagon, or a dodecagon.*

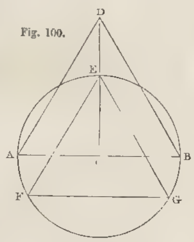
Let A D G E, &c. (Fig. 99), be the given circle. From any point A in the circumference of the circle, with the radius A B, equal to that of the given circle, describe the arc C B D, and join C D. From C as a centre, with the radius C D, cut the circumference at E, also join D E and E C, then C D E will be the equilateral triangle required. For the hexagon, apply the radius A B six times round the circumference of the given circle, and the figure A C F E G D will be the hexagon sought. Bisect the arc A C in *h*, and join A *h*, *h* C, then either of these lines applied twelve times successively to the circumference, will form the dodecagon, and be contained in the circle.

Fig. 99.



Another Method of inscribing an equilateral triangle. — Let A B E (Fig. 100) be the given circle, and C its centre. Draw the diameter A B, upon which describe the equilateral triangle A D B: join C D, cutting the circumference in E; then through E draw E F parallel to D A, and E G parallel to D B, and meeting the opposite circumference in F and G; join F G. The triangle E F G is equilateral, and inscribed in the circle A B E.

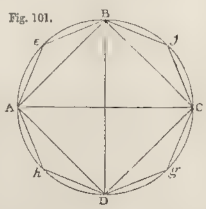
Fig. 100.



PROBLEM XLIV.—*In a given circle to inscribe a square or an octagon.*

Let A B C (Fig. 101) be the given circle. Draw the diameters A C and B D at right angles to each other. Join A B, B C, C D, and D A: these lines will form the square A B C D. Bisect the arcs A B, B C, C D, and D A, in the points *e*, *f*, *g*, and *h*. Join A *e*, *e* B, B *f*, &c., and the octagon will be completed and inscribed, as required.

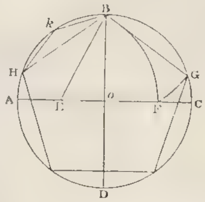
Fig. 101.



PROBLEM XLV.—*To inscribe a regular pentagon or a regular decagon in a given circle.*

Let A B C D (Fig. 102) be the given circle, of which *o* is the centre. Draw the diameters A C B D at right angles to each other: bisect the radius A *o* in E, and from E, with the distance E B, describe the arc B F, cutting A C in F; also from B as a centre, with the distance B F, describe the arc F G, cutting the circumference in G. Join G B, and four such chords applied from G round the circumference will terminate in B, and form the pentagon. Bisect the arc B H in *k*: join B *k* and H *k*. If the same process be repeated with each of the arcs, or if either of the chords B *k* or *k* H be carried round the circumference, a decagon will be inscribed in the circle, as required.

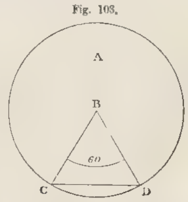
Fig. 102.



PROBLEM XLVI.—*To inscribe a regular polygon in a given circle, by finding the angle at the centre.*

Divide 360 degrees, or the whole circumference of the circle, by the number of sides in the given polygon, and the quotient will be the number of degrees contained in the angle at the centre. Suppose, for example, that the polygon to be inscribed in the given circle A is a regular hexagon. By a scale of chords, or any other instrument for measuring angles, make an angle at B the centre of the circle, equal to 60 degrees, the legs of which when produced meet the circumference at C and D. Draw the chord C D; this line applied six times successively to the circumference of the given circle, will constitute the required hexagon. To find the angle of any polygon, we have only to subtract the angle at its centre from 180 degrees. For instance, the angle at the centre of a hexagon being 60 degrees, subtract 60 from 180, and the remainder is 120, the interior angle of the hexagon, or the angle formed by any two of its adjacent sides. Suppose the required polygon to be an octagon, the angle at the centre of this figure is found, as directed above, to be 45 degrees, which being subtracted from 180, gives for the remainder 135 degrees, the angle formed by the adjoining sides of the octagon.

Fig. 103.



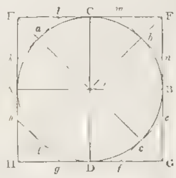
Or, more simply, for the hexagon draw any radius C D (Fig. 103), and upon C D describe the equilateral triangle B C D, which, being repeated round the circle, will complete the hexagon.

Again, to find the angle at the base of the elementary triangle of any regular polygon. Find the interior angle of the polygon, by the rules already given, and one-half of that angle will be the angle at the base of its elementary triangle. As an example, the interior angle of a hexagon is 120 degrees, one half of which is 60 degrees; this is the angle at the base of the elementary triangle, upon which the hexagon is constructed. Also the angle of the octagon is 135 degrees, one-half of which is $67\frac{1}{2}$, or 67 degrees 30 minutes—the angle at the base of its elementary triangle.

Problem XLVII.—*To describe a square, as also an octagon, about a given circle.*

Let A B C D (Fig. 104) be the given circle. Draw the diameters A B and C D, intersecting each other at right angles: through the extremities of these diameters draw the lines E C F, F B G, G D H, and H A E, at right angles to A B and C D, and intersecting at the angular points E, F, G, and H: the figure E F G H is the circumscribing square. Join E G and F H, cutting the circle in the points *a*, *b*, *c*, and *d*; also through these points draw the lines *e f*, —, *g h*, —, *k l*, —, *m n*, and —, at right angles to their respective radii, and they will complete the octagon, which is also described about the circle A D B C.

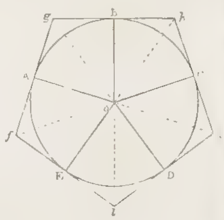
Fig. 104.



Problem XLVIII.—*About a given circle to describe a regular polygon.*

Let it be required to describe a regular pentagon about a given circle (Fig. 105), whose centre is *o*. Divide the circumference into five equal parts—the number of sides contained in the given polygon—and from the points A B C D and E, thus found, draw to the centre *o* the radii A *o*, B *o*, C *o*, D *o*, and E *o*; also through these same points draw the lines *f* A *g*, *g* B *h*, *h* C *k*, *k* D *l*, and *l* E *f* perpendicular to their respective radii, and intersecting one another in the angular points *f*, *g*, *h*, *k*, and *l*: a regular pentagon will be formed, and be described about the circle.

Fig. 105.

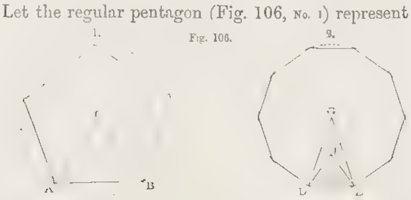


Upon the same principle, regular polygons of any number of sides may be described about given circles.

Problem XLIX.—*Any regular polygon being given, to describe another having the same perimeter, but twice the number of sides.*

Let the regular pentagon (Fig. 106, No. 1) represent the

Fig. 106.

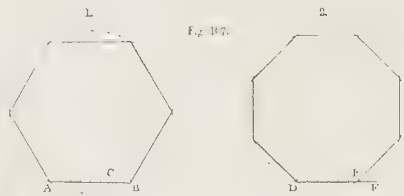


given polygon: bisect any two of its adjacent angles, as at A and B, by the straight lines A C and B C, intersecting each other in C; then A B C is the elementary triangle of the pentagon, and C its centre. Draw the straight line D E (No. 2) equal to half A B (No. 1), and upon D E describe the triangle D E F (Problem XV.), similar to A B C. Bisect the base line D E by a perpendicular drawn through the vertex F, and produce this perpendicular upwards to G, making F G equal to F E or F D. Join also G D and G E; then G D E will be the elementary triangle of the decagon, and G the centre. From G, with a radius equal to G D or G E, describe a circle and ten chords, each equal to D E: the base of the elementary triangle, applied successively to the circumference, will produce a decagon having the same perimeter, and, of course, twice the number of sides as the given pentagon. That the decagon thus constructed will have the same perimeter or *contour* as the pentagon, is evident, seeing that each side of the ten-sided figure is made equal to half a side of the five-sided figure or pentagon.

Problem L.—*Any regular polygon being given, to construct another having the same perimeter, but containing any different number of sides.*

For example, let it be required to construct a regular octagon, having its perimeter equal to that of a given hexagon. Divide A B, a side of the given polygon (Fig. 107, No. 1), into eight equal parts, the number of sides in the required figure. Let A C be six of these equal parts: draw D E (No. 2) equal to A C, or to six-eighths of the given line

Fig. 107.



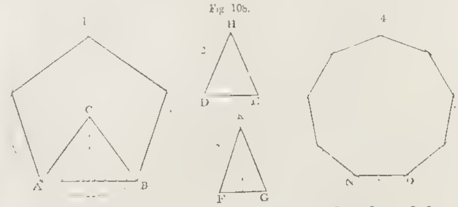
A B; and upon D F, by Problem XXXVII., describe a regular octagon; its perimeter will be equal to that of the given hexagon.

In the preceding example the figure required has a greater number of sides than that which is given; but to reverse the process, let D E (No. 2) be the side of a given octagon, and let a hexagon be the polygon required. Divide the line D E into six equal parts, and extend it to F, so as to make E F equal to two of these parts, or the whole line D F equal to eight of these same parts, and consequently equal to A B, which also contains eight parts, each equal to the corresponding divisions on D E. Thus, whatever may be the difference between the number of sides in the given and proposed polygons, it is only necessary to divide a side of the given figure into the same number of equal parts as there are sides in the one required— extending or contracting the given side by the number of equal parts, indicating the excess of the one figure above the other in the number of sides.

Problem LI.—*Any regular polygon being given, to describe another having the same area, but a different number of sides.*

Suppose the given polygon to be a regular pentagon: let it be required to describe a regular nonagon, the area of which shall be equal to that of the pentagon (Fig 108, No. 1). Find, by Problem XLIX., the elementary triangle A B C of the given pentagon. Divide the base A B into

Fig 108.



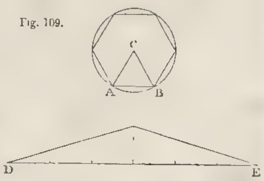
nine equal parts, and make D E (No. 2) equal to five of these parts; then upon D E, as a base, construct the triangle D E H, having its altitude or perpendicular height equal

to that of the triangle A B C. The triangle thus found will be five-ninths of A B C. Describe another triangle F G K (No. 3), by Problem XLVI., having its altitude equal to that of D E H, and its vertical angle 40 degrees, which is the angle at the centre of a regular nonagon. Again, by Problem X., find a mean proportional between the bases D E and F G of the triangles D E H and F G K, and it will be a side of the nonagon required. Draw a line N O (No. 4), equal to the mean proportional thus found, and upon it describe, by Problem XXXVII., a regular nonagon (No. 4), and its area will be equal to that of the given pentagon (No. 1).

PROBLEM LII.—*To find the area of any regular polygon.*

Let the given figure be a hexagon: it is required to find its area. Bisect any two adjacent angles, as those at A and B (Fig. 109), by the straight lines A C and B C, intersecting in C, which will be the centre of the polygon. Mark the altitude of this elementary triangle, by a dotted line drawn from C perpendicular to the base A B; then multiply together the base and altitude thus found, and this product by the number of sides: half gives the area of the whole figure.

Fig. 109.

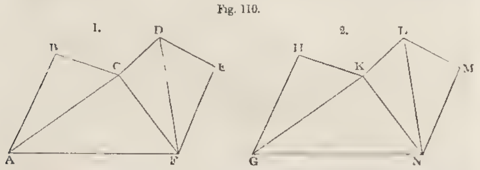


Or otherwise, thus.—Draw the straight line D E, equal to six times, *i. e.*, as many times A B, the base of the elementary triangle, as there are sides in the given polygon. Upon D E describe an isosceles triangle, having the same altitude as A B C, the elementary triangle of the given polygon: the triangle thus constructed is equal in area to the given hexagon; consequently, by multiplying the base and altitude of this triangle together, half the product will be the area required. The rule may be expressed in other words, as follows:—The area of a regular polygon is equal to its perimeter, multiplied by half the radius of its inscribed circle, to which the sides of the polygon are tangents.

PROBLEM LIII.—*To describe any figure similar and equal to a given rectilineal figure.*

Let A B C D E F (Fig. 110, No. 1) be the given rectilineal figure: it is required to construct another that shall be equal and similar to it. Divide the figure into triangles, by the diagonals A C, C F, and D F: draw a straight line

Fig. 110.



G N (No. 2) equal to A F, and upon G N construct the triangle G K N, the three sides of which shall be respectively equal to those of the triangle A C F. Also upon G K, which is by construction equal to A C, describe the triangle G H K, having its sides G H and H K respectively equal to A B and B C. Again, upon K N, which is equal to C F, describe the triangle K L N, having its sides K L and L N respectively equal to C D and D F. And lastly, upon L N, which is equal to D F, construct the triangle L M N, having its sides L M, M N respectively equal to D E and E F; then G H K L M N will be the figure required.

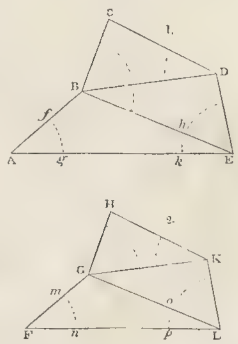
Any rectilineal figure may thus be described equal and similar to a given rectilineal figure, *i. e.*, by dividing the figure or polygon into triangles, and upon a line equal to one of the given sides, constructing a succession of triangles equal and similar to the corresponding triangles into which the original figure is divided.

The simplest method of constructing a triangle equal and similar to another, is the following:—Let A C F (Fig. 110, No. 1) be the given triangle. Take G N equal to A F; from G as a centre, with a radius equal to A C, describe an arc, and from N, with a radius equal to C F, describe another arc cutting the former in K; then, by joining K G and K N, the triangle K G N is formed equal and similar to A C F. The same process may be repeated, till all the triangles in No. 1 are exhausted.

PROBLEM LIV.—*On a given line to describe a figure similar to a given rectilineal figure.*

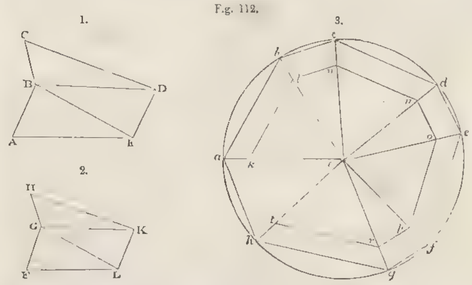
Let A B C D E (Fig. 111, No. 1), be the given rectilineal figure, and F L (No. 2) the given straight line. Divide A B C D E into triangles by the diagonals B D and B E. From the angular point A, with any convenient radius, describe the arc $f\,g$; and from F (No. 2), one extremity of the given line F L, with the same radius, describe the arc mn, making it equal to $f\,g$; likewise from the angular point E (No. 1), with any radius, describe the arc $h\,k$, and from the point L, with the same radius, draw the arc $o\,p$ equal to $h\,k$; then through the points F and m, as also through L and o, draw the straight lines F G and L G, intersecting in G, and the triangle F G L thus found will be similar to A B E. In like manner, upon G L construct the triangle G K L, and upon G K construct the triangle G H K, similar to the corresponding triangles B D E and B C D (No. 1); then F G H K L will be the figure required.

Fig. 111.



Another mode of solution.—Let A B C D E (Fig. 112, No. 1) be the given figure, as before, and F L (No. 2) the given line, upon which a figure similar to A B C D E is to be constructed. Divide the given figure into the triangles A B E, D E B, and B C D. From o as a centre (No. 3), with any moderate radius, describe the circle $a\,b\,c\,d$, &c. From the point a, round the circumference draw the chords

Fig. 112.

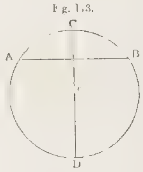


ab, bc, cd, de, ef, fg, and gh, respectively equal to the lines AE, AB, BE, DE, DB, CD, and BC (No. 1). Draw also the radii ao, bo, co, do, &c. (No. 3). On the line ao find ok, a fourth proportional to the lines ab, ao, and the given line FL; then through the point k draw kl parallel to the chord ab, and it will be equal by construction to FL (No. 2). From the point l. where the line kl meets the radius bo, draw lm parallel to bc; draw also the parallels mn, no, op, pr, and rt, meeting the different radii in the points m, n, o, p, r, and t. Then upon FL as a base construct the triangle FGL, having its sides FG and GL equal to the lines lm and mn. Also upon GL describe the triangle GKL, having its sides KL and GK equal to no and op. Again, upon GK as a base construct the triangle GKH, having its sides GH and HK respectively equal to the lines pr and rt, and the rectilineal figure FGHKL thus formed will be similar to the given rectilineal figure ABCDE.

CONSTRUCTION OF CIRCLES, CIRCULAR FIGURES, &c.

PROBLEM LV.—*To find the centre of a given circle.*

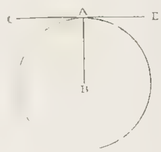
Fig. 113.



Let ACBD (Fig. 113) be the given circle. Draw the chord line AB between any two points A and B in the circumference: bisect the line AB by a perpendicular line CD, produced both ways to meet the circumference in C and D. Again, bisect the perpendicular CD in e, and e is the centre of the circle.

PROBLEM LVI.—*To draw a tangent to a given circle, that shall pass through a given point in the circumference.*

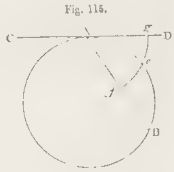
Fig. 114.



Let A (Fig. 114) be a given point in the circumference of the circle, whose centre is B. Draw the radius AB, and through the point A draw the line CD perpendicular to AB, and it will be the tangent required.

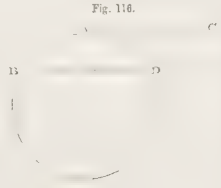
PROBLEM LVII.—*To draw a tangent to a circle, or any segment of a circle, through a given point, without having recourse to the centre.*

Fig. 115.



Let A (Fig. 115) be a given point in the circumference of a circle. Take any other point in the circumference, as B: join AB, and bisect the arc AB in e: join also A e: then from A as a centre, with a radius equal to A e, the chord of half the arc, describe the arc feg, making eg equal to ef; then through the points A and g draw the straight line CAD, and it will be the tangent sought.

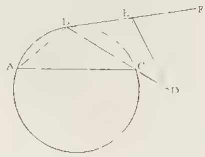
Fig. 116.



Another Method.—Let A (Fig. 116) be a given point in the circumference of a circle. Take any two other points, as B and D in the circumference, equidistant from A: join BD, and through A draw AC parallel to BD· AC is a tangent to the circle.

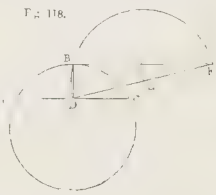
Other methods of drawing a tangent to a circle, from a given point in the circumference, without finding the centre.—Let ABC (Fig. 117) be the given circle, and B the given point in the circumference, from which the tangent is to be drawn, without finding the centre. Take any other two points A and C, in the circumference, one on each side of B, and join them so as to form the triangle ABC. Produce BC to D, making BD equal to AC, and from B, with a radius equal to AB, describe an arc; and from D, with the radius BC, describe another arc intersecting the former in E. Through E draw BEF, which is the tangent sought. For, join DE, and as the triangle DEB is by construction equal and similar to the triangle ABC, of which the angle DBE is equal to the angle BAC, the angle in the alternate segment of the circle, BF must consequently be a tangent to the circle at the point B.

Fig. 117.



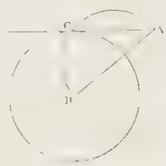
Otherwise, thus.—Let ABC (Fig. 118) be the given circle, and B the given point, as before. Take any two points A and C in the circumference, *equidistant* from B; join AC, and bisect it in D. From B and D as centres, with the same radius of any convenient length, describe arcs intersecting in E. From E, with the distance EB or ED, describe the semicircle DBF, and join DE, and produce it to meet the semi-circumference in F. Join BF, and it will be a tangent to the circle. For, join BD, and as DBF is an angle in a semicircle, it must be a right angle, and as one of its sides, BD produced, would pass through the centre of the circle, BF must necessarily be a tangent to that circle.

Fig. 118.



PROBLEM LVIII.—*To draw a tangent to a circle from a given point without the circumference.*

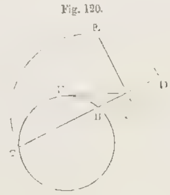
Fig. 119.



Let A (Fig. 119) be a given point without a given circle, of which B is the centre; join AB, and upon this line, as a diameter, describe a semicircle cutting the given circumference in C; join AC, and it will be the tangent required.

Another method, without finding the centre of the given circle.—Take any point C (Fig. 120) in that part of the given circumference which is concave towards A; join AC, intersecting the opposite part of the circumference in B; produce CA to D, so as to make AD equal to AB. Upon CD, as a diameter, describe a semicircle; draw AE at right angles to CD, meeting the semi-circumference in E. From A as a centre, with the radius AE, cut the given circle in F; join AF, and it will be the tangent sought.

Fig. 120.



PROBLEM LIX.—*A circle and a tangent being given, to find the point of contact.*

Let ABC (Fig. 121) be a given circle, of which the centre

is E, and C D a tangent to that circle it is required to find the point C. In C D take any point f: join E f, and bisect it in g; then from g, with the radius g E or $g\,f$, describe a semicircle intersecting the tangent and circumference in C, which is the point of contact sought.

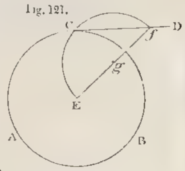


Fig. 121.

PROBLEM LX.—*To describe the circumference of a circle through three given points.*

Let A, B, and C (Fig. 122), be the given points not in a straight line. Join A B and B C: bisect each of the straight lines A B and B C by perpendiculars meeting in D; then A, B, and C are all equidistant from D; therefore a circle described from D, with the radius D A, D B, or D C, will pass through all the three points as required.

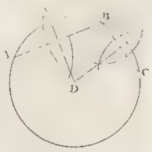


Fig. 122.

PROBLEM LXI.—*Given the span or chord line, and height or versed sine of the segment of a circle, to find the radius.*

Let A B (Fig. 123) be the given span or chord line: bisect it in D by the perpendicular line C E, and make D C equal to the given height or versed sine. Join A C, and also bisect it by a line drawn perpendicular to it, and meeting D E in F: join F A, then from F as a centre, with the radius F A or F C, describe the arc A C B, which will be the segment required.

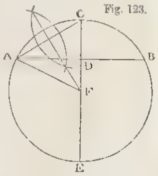


Fig. 123.

Another Method.—Let A B (Fig. 124) be the given chord. Bisect it (as before) in D by the line C E, drawn at right angles to it. Make D C equal to the given height or versed sine: join A C, and from the point C, with any radius less than A C, describe the arc $f\,g$; and from A, with the same radius, draw the arc $h\,k$, making it equal to $f\,g$. Through the point k draw the line A E, which will meet C E in E; then the angle C A E will be equal to the angle A C E. Also from E, with the radius E A or E C, describe the arc A C B, which will form the segment of a circle subtended by the given chord A B, and having the given height or versed sine D C.

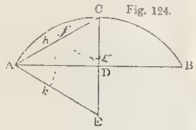


Fig. 124.

Another Method.—Let A B (Fig. 125) be the given chord; and let the line L represent the given height or versed sine of the arc. Bisect A B in C, and draw C D perpendicular to A B, and equal to the line L or given height of the arc. Draw the line A E, equal to C D, and making any angle with A B: join C E, and produce A E to F, so as to make E F equal to A C. Through F draw F G parallel to C E, and meeting A B produced in G. Produce D C to H, making C H equal to C G; then bisect D H in o, and it will be the centre of the arc; that is, an arc described from o, with the radius D o, will pass through the points A and B, and form the segment A D B.

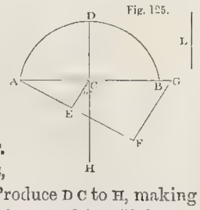


Fig. 125.

Note.—The radius of an arc or arch, of which the span, or chord, and height are given, may be obtained by calculation. Thus, divide the square of half the chord by the height of the arc: to the quotient add the height of the arc, and the sum will be the diameter of the circle, or double the radius sought. For example, suppose the chord A B (Fig. 123) 22 feet, and the versed sine C D 7 feet; then half of 22 is 11, the length of the half chord D A or D B; and 11 squared is 121, which, divided by 7, gives $17\frac{2}{7}$ for the quotient then 7 added to $17\frac{2}{7}$; is $24\frac{2}{7}$, the diameter of the circle C E, one half of which, $12\frac{1}{7}$ feet, is the length of the radius F A or F C.

PROBLEM LXII.—*The chord of an arc, and also the radius of the circle, being given; to find the height or versed sine of that arc.*

Let A C (Fig. 126) be the given chord: from the extremities A and C, with the given radius, describe arcs intersecting each other in D: join D A and D C. Bisect A C in E: join also D E, and extend it till D B be equal to D A or D C; then B E will be the height of the arc required.

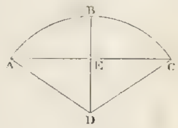


Fig. 126.

Or otherwise, thus.—Having found D as above; from this centre D, with the given radius, describe the arc A B C; and having bisected A C in E, join D E, and produce it to meet the circumference in B; B E is the versed sine, or height of the arc as before.

Or by calculation, subtract the square root of the difference between the square of the radius and that of half the chord from the radius, and the remainder is the height of the arc.

As an example, suppose the half chord E A or E C to be 16 feet, and the radius 20 feet; then the square of 20 is 400, and the square of 16 is 256, which subtracted from 400, gives 144 of a remainder, the square root of which is 12: this subtracted from 20 leaves a remainder of 8, the height or versed sine E B.

Another Method.—Let A B (Fig. 127) be the given chord; and let the straight line L represent the given radius. Produce A B to C, so as to make A C double the length of the line L; and on A C, as a diameter, describe a semicircle. Bisect A B in D, and draw C E at right angles to A C, and equal to A D or D B; then through E draw E F parallel to B C, cutting the semicircle in the point F. From F let fall upon A C the perpendicular F G.

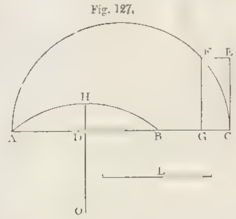


Fig. 127.

Again, from D draw D H at right angles to A B, and equal to C G; then D H is the height or versed sine of the arc. Let H D be extended to O, so as to make H O equal to the given radius L; an arc described from O as a centre, with the radius O H, will also pass through A and B, the extremities of the given chord.

Note.—Though this method may appear somewhat round about, it is at least novel, and can be demonstrated on strictly geometrical principles.

PROBLEM LXIII.—*To describe a circle that shall touch two straight lines given in position, and one of them at a given point.*

Let A B and A C (Fig. 128) be the given straight lines, and D a given point in A B. If the lines are not parallel, they will meet if produced. Let them meet in the point A. From A C cut off A E, equal to A D; and in D B take any point F, and make E G equal to D F. Join E F and D G,

intersecting in the point *o*. From *o*, with the distance *o* D or *o* E, which are equal, describe a circle cutting the given line A B in the points D and H, and A C in E and L. Draw the radius H *o*, and extend it to meet the circumference in K; join also L *o*, and produce it to meet the opposite circumference in M. Again, join E M and D K, intersecting in S. From the point of intersection S, as a centre, with the radius S E or S D, which are equal, describe the circle E N D, and it will touch both the given lines A B and A C, and the former in the given point D.

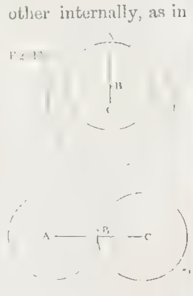
Another Method.—Let A B and A C (Fig. 129) be the given lines, and D the given point in A C, as before. Make A E equal to A D: draw D G at right angles to A B, and meeting C A in G. Cut off A F equal to A G, and join E F, intersecting D G in H. From H, with the radius H E or H D, describe the circle E K D, and it will touch the given lines, and A B in D the given point.

Fig. 129

The plans here given of drawing a tangent from a given point in the circumference, without having recourse to the centre, are not to be found in any book of practical geometry that we are acquainted with. They avoid the somewhat clumsy resource of gauging arcs with the compasses in order to obtain equal angles, which detracts from the elegance of the solution of a problem. The exhibition of arcs ought, if possible, to be avoided, except when they intersect, for the purpose of obtaining certain points. In other cases they mar the effect of the handsomest figures. This consideration induced having recourse to the circle in the construction of similar figures.

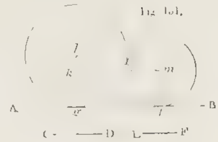
PROBLEM LXIV.—*Two circles touching each other being given, to find the point of contact.*

First, let the circles touch each other internally, as in Fig 130 (No. 1). Find C and B, the centres of these circles, by Problem LV.: join C B, and produce it to meet both the circumferences in A. This will be the point of contact between the two circles. Second, let the circles touch each other externally, as in No. 2, then the point B, where the line A C intersects the common boundary of the two circles, is the point of contact; A and C being their centres.



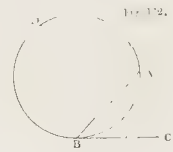
PROBLEM LXV.—*To describe with given radii two contiguous circles, which shall also touch a given line.*

Let A B (Fig. 131) be the given line, and C D and E F the given radii. From any point *g* in A B, erect a perpendicular *g h* equal to C D, the greater radius, and set off *g k* equal to E F, the lesser. Through *k* draw *k m* parallel to A B; and from *h*, the extremity of the perpendicular *g h*, with a distance equal to the sum of C D and E F, describe an arc intersecting the parallel *k m* in the point *m*. Let fall the line *m l* perpendicular to A B, and it will be equal to E F, one of the given radii. From *m*, with the radius *m l*, describe a circle. Again, from *h*, with the radius *g h*, describe also a circle, and it will touch the former in *n*, while *g* and *l* are the respective points of contact with the given line A B.



PROBLEM LXVI.—*From a given circle to cut off a segment, that shall contain an angle equal to a given angle.*

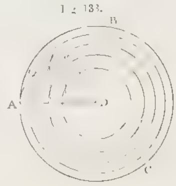
Let A B D (Fig. 132) represent the given circle. From any point B in the circumference, draw a tangent B C; also from the point of contact B draw a chord line B A, so as to form an angle equal to the given angle; then the chord A B will divide the circle into two segments. In that segment having its portion of the circumference concave towards the tangent B C, take any point D, and join A D and D B: the angle A D B in this alternate segment is equal to A B C, which was made equal to the given angle; therefore A D B is the segment required.



Note.—If a tangent and chord be drawn from any point in the circumference of a circle, the angle formed by these lines will be equal to the vertical angle of any triangle having the chord for its base, and its vertex in any part of the circumference which bounds the alternate segment of the circle.

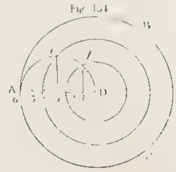
PROBLEM LXVII.—*To divide a given circle into any number of equal or proportional parts by concentric divisions.*

Let A B C (Fig. 133) be the given circle, to be divided into five equal parts. Draw the radius A D, and divide it into the same number of parts as those required in the circle; and upon the radius thus divided, describe a semicircle: then from each point of division on A D, erect perpendiculars to meet the semi-circumference in *e*, *f*, *g*, and *h*. From D, the centre of the given circle, with radii extending to each of the different points of intersection on the semicircle, describe successive circles, and they will divide the given circle into five parts of equal area as required; the centre part being also a circle, while the other four will be in the form of rings.



PROBLEM LXVIII.—*To divide a circle into three concentric parts, bearing to each other the proportion of one, two, three, from the centre.*

Draw the radius A D (Fig. 134), and divide it into six equal parts. Upon the radius thus divided, describe a semicircle: from the first and third points of division, draw perpendiculars to meet the semi-circumference in *e* and *f*. From D, the centre of the given circle, with radii extending to *e* and *f*, describe circles which will divide the given circle into three parts, bearing to each other the same proportion as the divisions on A D,

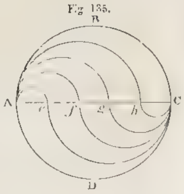


which are as 1, 2, and 3. In like manner, circles may be divided in any given ratio by concentric divisions.

PROBLEM LXIX.—*To divide a given circle into any number of parts, equal to each other both in area and perimeter.*

Let A B C D (Fig. 135) be the given circle, which we shall suppose is to be divided into five equal and isoperimetrical areas. Draw the diameter A C, and divide it into five equal parts, at the points *e*, *f*, *g*, and *h*. Upon A *e*, A *f*, A *g*, and A *h*, as diameters, describe a succession of semicircles, all upon the same side of the diameter A C. Then reversing the operation, by commencing at C, describe upon C *h*, C *g*, C *f*, and C *e* the same number of semicircles, on the contrary side of A C: these opposite semicircular lines will meet in the points *e*, *f*, *g*, and *h*, forming the five equal and isoperimetrical figures into which the circle was to be divided.

Fig. 135.

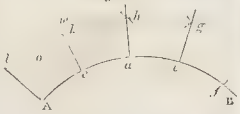


Note.—It ought to be understood that the diameter A C in the last example, and the directing lines in the two preceding, form no part of the boundary lines by which the respective circles are divided into equal or proportional parts.

PROBLEM LXX.—*An arc of a circle being given, to raise perpendiculars from any given points in that arc without finding the centre.*

Let A B (Fig. 136) be the given arc, and A, *c*, *d*, and *e* the given points from which the perpendiculars are to be erected. In the arc *e* B take any point *f*, so as to make *e f* equal to *e d*: from *d* and *f* as centres, with any equal radii greater than half the distance between them, describe arcs intersecting each other in *g*: join *e g*, and it will be one of the perpendiculars required: *d h* and *c k* are found in the same manner. In order to raise a perpendicular from A, the extremity of the arc, suppose the perpendicular *c k* to be erected: from *c*, with the distance *c* A, describe the arc A *m*; and from A, with the same radius, describe *c l*, intersecting A *m* in *o*: make *o l* equal to *o m*, and join A *l*, which will be the perpendicular sought.

Fig. 136.

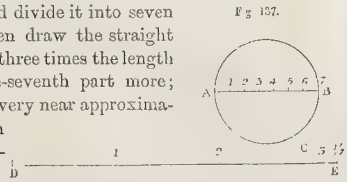


Note.—The perpendicular to any curve, means a line perpendicular to the tangent or chord of that curve.

PROBLEM LXXI.—*To draw a straight line equal to the circumference of a given circle.*

Let A B C (Fig. 137) be the given circle. Draw the diameter A B, and divide it into seven equal parts: then draw the straight line D E, equal to three times the length of A B, and one-seventh part more; and it will be a very near approximation to the length of the circumference.

Fig. 137.

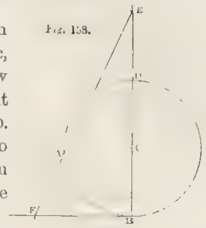


The diameter of the circle is to the circumference in the ratio of 1 to 3·1415926, &c. As the decimals might be continued to infinity, it will be seen that the exact proportion cannot be obtained. The simplest approximation to this ratio is that of 7 to 22, or of 1 to $3\frac{1}{7}$, and the preceding line is drawn according to this last proportion, which is sufficiently near the truth for most practical purposes.

PROBLEM LXXII.—*To draw a straight line equal to any given arc of a circle.*

Let A B (Fig. 138) be the given arc. Find C the centre of the arc, and complete the circle A D B. Draw the diameter B D, and produce it to E, until D E be equal to C D. Join A E, and extend it so as to meet a tangent drawn from B in the point F; then B F will be nearly equal to the arc A B.

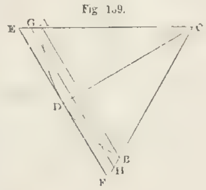
Fig. 138.



The following method of finding the length of an arc is equally simple and practical, and not less accurate than the one given above.

Let A B (Fig. 139) be the given arc. Find the centre C, and join A B, B C, and C A. Bisect the arc A B in D, and join also C D; then through the point D draw the straight line E D F, at right angles to C D, and meeting C A and C B produced in E and F. Again, bisect the lines A E and B F in the points G and H. A straight line G H, joining these points, will be a very near approach to the length of the arc A B.

Fig. 139.



Note.—Seeing that in very small arcs the ratio of the chord to the double tangent, or, which is the same thing, that of a side of the inscribed to a side of the circumscribing polygon, approaches to a ratio of equality, an arc may be taken so small, that its length shall differ from either of these sides by less than any assignable quantity; therefore, the arithmetical mean between the two must differ from the length of the arc itself, by a quantity less than any that can be assigned. Consequently the smaller the given arc, the more nearly will the line found by the last method approximate to the exact length of the arc. If the given arc is above 60 degrees, or two-thirds of a quadrant, it ought to be bisected, and the length of the semi-arc thus found being doubled, will give the length of the whole arc.

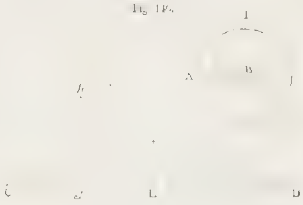
Since the two preceding problems cannot be exactly solved by any rule founded upon geometrical principles, the two following methods may also be used, which will give the length of a circular arc, or indeed of any curved line whatever, as accurately perhaps as it can possibly be obtained. The first is to bend a thin slip of wood or any other elastic substance round the curve, then this slip extended out at length will be a very near approach to the length required. The second is to take a small distance between the compasses, and suppose the curve to contain this distance any number of times with a remainder. Upon a straight line repeat this distance, or chord, the same number of times, and transfer also the remainder from the curve to the straight line: the straight line thus extended will be very nearly equal to the given curve. It is obvious that if a given curve be divided into any number of equal parts or arcs, and if the chords of these arcs be transferred to a straight line, the line thus formed must be somewhat less than the curved line, as the chord of an arc, however small, can never be exactly equal to the arc itself. It is also evident, however, that the smaller the distance between the points, and the more numerous the parts taken on the curve, the more nearly will the straight line to which these parts, or rather their chords,

are transferred, approximate to the length of the curved line itself.

Problem LXXIII.—*To construct a triangle equal to a given circle.*

Let Fig. 140 (No. 1) be the given circle, of which the radius is A B. Draw by Problem LXXI. the straight line C D (No. 2), equal to the circumference of the circle: bisect it in E, and erect E F perpendicular to C D, and equal to the radius A B: join C F and D F, and C F D is the triangle required.

Fig. 140.

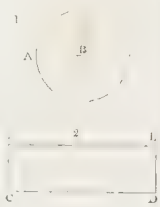


Or, as shown by the dotted lines, make C E, which is equal to the semi-circumference, the base of the triangle, and make its altitude $g\,h$ equal to twice A B, or to the diameter of the circle: join C h and E h, then the triangle C E h is also equal to the given circle. Hence the area of a circle is equal to the product of its circumference by half the radius; or to the product of its semi-circumference by half the diameter or radius.

Problem LXXIV.—*To describe a rectangle equal to a given circle.*

Let Fig. 141 (No. 1) be the given circle, of which A B is the radius. By Problem LXXI. draw the straight line C D (No. 2), equal to the semi-circumference of the circle, and upon this line as a base construct the rectangle C D E F, having its altitude D E equal to A B, the radius of the given circle, and it will be such as is required.

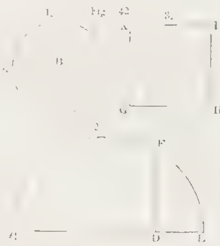
Fig. 141.



Problem LXXV.—*To describe a square equal to a given circle.*

Let Fig. 142 (No. 1) be the given circle, which has A B for its radius. Draw the line C D (No. 2), equal to the semi-circumference of the given circle. Produce C D to E, making D E equal to the radius A B. Upon the whole line D E describe a semicircle, and draw D F perpendicular to D E, and meeting the semi-circumference in F. Again, draw the straight line G H (No. 3), equal to D F, and upon this line as a base describe the square G H I K, and its area will be equal to that of the given circle.

Fig. 142.



Problem LXXVI.—*To describe a square or a rectangle that shall be equal to a given circle.*

Let A B C (Fig. 143, No. 1) be the given circle, of which D is the centre. Draw the diameter A D C, and draw the double tangent G F H parallel and equal to A C: join D G and D H, cutting the circumference in K and L. Bisect G K and H L in M and N, and join M N. Draw the line P R (No. 2), equal to M N, and upon it describe the square P R S T, which will be very nearly equal to the area of the circle A B C. Again, draw any indefinite line V W (No. 3). In it take any point X: draw X Y at right angles to V W, and equal to M N or P R. In X W take any point Z, and

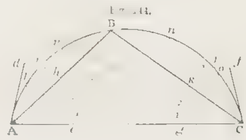
Fig. 143.

from Z, with the radius Y Z, describe the semicircle Q Y W. Cut off X a, equal to X Q, and describe the rectangle $a\,b$ W X: it will be equal to the area of the circle.

Problem LXXVII.—*To describe an arc of a circle through three given points, without finding the centre.*

Let A, B, and C (Fig. 144), be three given points, not in a straight line. Connect these points, so as to form the triangle A B C, the base of which, A C, will represent the chord of the proposed arc. From A and C, with equal radii, describe the arcs $d\,e$ and $f\,g$, cutting A B and B C in the points h and k. Make the arc $k\,f$ equal to the arc $h\,e$, and $d\,h$ equal $g\,k$. Divide each of these four arcs into the same number of equal parts. Then from A and C, the extremities of the chord, through the first and second divisions on the arcs $d\,h$ and $k\,g$, draw straight lines, intersecting each other respectively in the points l and m. In like manner, from A and C, through the first and second divisions on the arcs $h\,e$ and $k\,f$, draw lines intersecting respectively in the points n and o. A curve line traced through the vertical angular points of the triangles thus formed, will be the arc required.

Fig. 144.

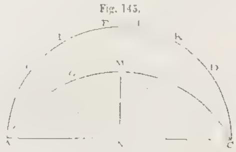


The vertical angles formed as above, are all equal by construction, and as they are upon the same base, they must (according to Euclid) be in the segment of a circle.

Note. The most expeditious, as also the most accurate method for tracing lines of this description, is the following. Having obtained a sufficient number of true points in the proposed curve, and having placed small nails in the several points, bend a thin slip of wood, or some other elastic substance, round these nails; then by drawing the pen along this slip on the side of the nails, the required curve line will be described.

Another Construction.—Let A, B, and C (Fig. 145) be the given points. Join them so as to form the triangle A B C. Upon A C, as a diameter, describe a semicircle, and produce A B and C B to meet the semi-circumference in the points D and E. From A set off on the semicircle the arc A F,

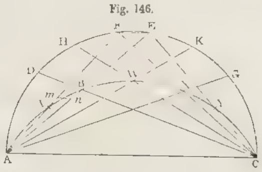
Fig. 145.



equal to the arc C D: join C F, and from A, with a radius equal to C B, cut the line C F in G: join A G, and produce it to meet the semicircle in H. Bisect the arcs D H and E F in the points K and L. Join A K and C L, intersecting each other in M. From M, the point of intersection, let fall upon A C the perpendicular M N, and it will be the altitude of the arc proposed.

Another Method.—Let A, B, and C (Fig. 146) be the given points, through which the arc is to be drawn. Join these points, so as to form the triangle A B C. Upon A C describe a semicircle, and extend the lines A B and C B to meet the semi-circumference in D and E. In the semicircle A D E C insert the chords C F and A G, equal to the chords A E and C D; then the point X, where C F and A G intersect, is a point in the proposed arc. Bisect each of the arcs D F and E G in the points H and K, and join A K and C H by lines intersecting in W, which is also a point in the curve. Join A F and C E, and draw the chord E F. From A F cut off F m, equal to B E, and through m draw $m\,n$ parallel to F E, and cutting A E in n. Again, from A F cut off F V, equal to E n; also from C E cut off C Y, equal to A V; then a curve traced through A, V, B, W, X, Y, and C, will describe the arc required.

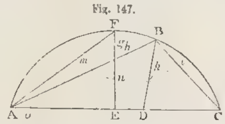
Fig. 146.



PROBLEM LXXVIII.—*Three points, neither equidistant nor in the same straight line, being given, through which the arc of a circle is to be described, to find the altitude of the proposed arc.*

Let A, B, and C (Fig. 147) be the given points. Connect them by the straight lines A B, B C, and A C, forming a triangle, the base of which, viz., A C, will be the chord of the arc whose height is to be determined. Bisect the vertical angle A B C by the line B D, meeting the base in D: bisect also the base A C in E, and from E draw the line E g perpendicular to A C. From the vertex B, with any radius, describe the arc $h\,k$, cutting the sides of the triangle A B D, in the points h and k; and from any point g in the perpendicular, with the same radius, describe the arc $m\,n$, making it equal to the arc $h\,k$: join $g\,m$, producing it to meet the base A C in o, or A C produced if necessary; then draw A F parallel to $o\,g$, and meeting it produced in F: E F is the extreme height or altitude of the arc proposed.

Fig. 147.



PROBLEM LXXIX.—*A segment of a circle being given, to produce the corresponding segment, or to complete the circle without finding the centre.*

Let A B C (Fig. 148) be the given segment; and let B be situated anywhere between A and C: join A B and B C: bisect the vertical angle at B by the straight line B D, meeting A C in the point D. From the extremities A and C, according to the method previously shown, describe angles on the contrary side of the chord A C, equal to the angle A B D or C B D, and produce the lines forming these angles from A and C to meet in the point E; then the vertex E of the triangle A C E is a point in the arc, which is to form the opposite segment. Find by Problem LXXVII any other number of points in the proposed arc, as f, g, h, and k, and join the extremities of the chord A C by a curved line passing through these points, and it will complete the circle as proposed.

Fig. 148

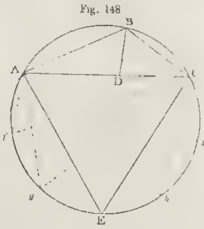
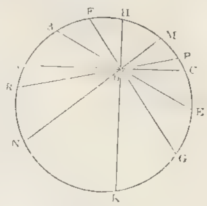


Fig. 149.

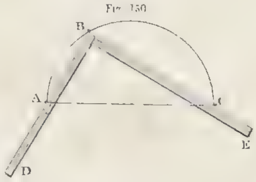


Another Method.—Let A B C (Fig. 149) be the given segment. From B draw the line B D, cutting A C at any angle, and produce it until D E be a fourth proportional to B D, D A, and D C. Take any other point F, and join F D, producing it to G, so as to make D G a fourth proportional to F D, D A, and D C. Find the points K, N, R, &c., in the same manner, and a curve line traced through these points will complete the circle.

PROBLEM LXXX.—*To describe a semicircle by means of a carpenter's square, or a right angle, without having recourse to its centre.*

At the extremities of the diameter A C (Fig. 150), fix two pins, then by sliding the sides of the square, or other right-angled instrument, D B, B E, in contact with the pins, a pencil held in contact with the point B will describe the semicircle A B C

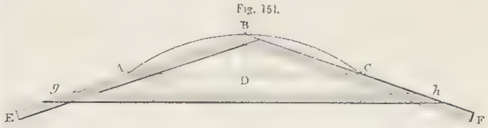
Fig. 150



PROBLEM LXXXI.—*To describe the segment of a circle by means of two rods or straight laths, the chord and versed sine being given.*

Take two rods, E B, B F (Fig. 151), each of which must be at least equal in length to the chord of the proposed segment A C: join them together at B, and expand them,

Fig. 151.

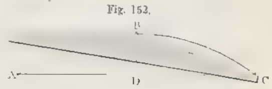


so that their edges shall pass through the extremities of the chord, and the angle where they join shall be on the extremity B of the versed sine D B, or height of the segment. Fix the rods in that position by the cross piece $g\,h$, then by guiding the edges against pins in the extremities of the chord line A C, the curve A B C will be described by the point B.

PROBLEM LXXXII.—*To describe a segment at twice by rods or laths, forming a triangle like the last, or by a triangular mould; the chord and versed sine being given.*

Let A C (Fig. 152) be the chord of the segment, and D B its height or versed sine: join C B, and draw B E parallel to A C, and make it equal to B C. Fix a pin in C and another in B, and with the triangle E B C describe the arc C B. Then remove the pin C to A, and by guiding the sides of the triangle against A and B, describe the other half of the curve A B.

Fig. 152.



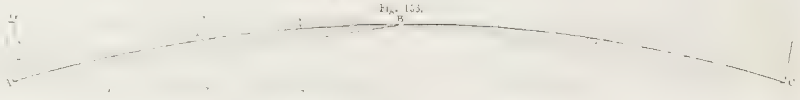
PROBLEM LXXXIII.—*Having the chord and versed*

sine of the segment of a circle of large radius given, to find any number of points in the curve by means of intersecting lines.

Let A C be the chord and D B the versed sine.

Through B (Fig. 153) draw E F indefinitely and parallel to A C: join A B, and draw A E at right angles to A B. Draw also A G at right angles to A C, or divide A D and E B into the same number of equal parts, and number the divisions from A and E respectively, and join the corresponding numbers by the lines 1 1, 2 2, 3 3. Divide also A G into the same number of equal parts as A D or E B, numbering the divisions from A upwards, 1, 2, 3, &c.; and from the points 1, 2, and 3, draw lines to B; and the points of intersection of these, with the other lines at *h*, *k*, *l*, will be points in the curve required. Same with B C.

Fig. 153.



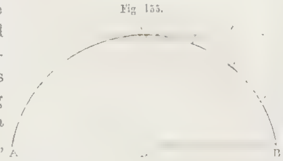
Another Method.—Let A C (Fig. 154) be the chord and D B the versed sine. Join A B, B C, and through B draw E F parallel to A C. From the centre B, with the radius B A or B C, describe the arcs A E, C F, and divide them into any number of equal parts, as 1, 2, 3: from the divisions 1, 2, 3, draw radii to the centre B, and divide each radius into the same number of equal parts as the arcs A E and C F; and the points *g*, *h*, *l*, *m*, *n*, *o*, thus obtained, are points in the required curve.

These methods, though not absolutely correct, are sufficiently accurate when the segment is less than the quadrant of a circle.

PROBLEM LXXXIV.—*The chord and versed sine of an arc being given, to find the curve, without having recourse to the centre.*

Let A B (Fig. 155) be the chord, and D C the versed sine. From C draw the tangent C *g* parallel to A B; and join C B, and bisect it in *f*. Make C *g* equal to C *f*, and from *f* and *g* raise perpendiculars to the lines C *f*, C *g*, intersecting in *e*, and *e* will be a point in the curve. Or, which is the same thing, bisect the angle *f* C *g* by the straight line C *e*, and to this draw the perpendicular from *f* or *g*, meeting it in *e*, which is the point required.

Fig. 155.

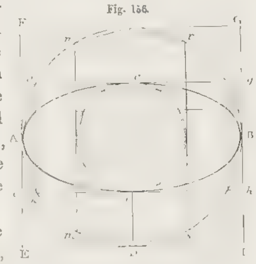


In the same way the point *h* is found by bisecting the angle *e* C *g*, then bisecting the line *e* C by a perpendicular cutting the bisecting line of the angle in *h*. As the segments C *e*, *e* B, are equal, another point may be found by joining *e* B, bisecting it by a perpendicular in *k*, and making the perpendicular or versed sine equal to that of the segment already found. Proceed thus until a sufficient number of points is obtained.

OF THE ELLIPSE, THE PARABOLA, AND THE HYPERBOLA.

THE ELLIPSE.—This curve is produced by the section of a cone through both of its sides, but not parallel to its base. If we expose to the sun a circle of wire, inscribed in a square traversed by two diameters which cross its centre at right angles, and so dispose of it that the rays of the sun may be perpendicular to the plane of the circle (Fig. 156), the shadow projected on a plane parallel to the plane of the circle, will produce a figure in all respects similar to the original figure of wire. But if the circle is turned on one of its diameters A B, without changing the situation of the plane on which the shadow is projected, then the shadow of the square E F G H shall be changed to a parallelogram *e f g h*, and the shadow of the circle A D B C to an ellipse A *d* B *c*.

Fig. 156.



2. The shadow of the axis A B is the major axis, and the shadow *c d* of C D is the minor axis of the ellipse.

3. As the circle may be so turned in regard to the sun and the plane on which the shadow is projected, that its shadow will be only a right line, it follows that, in turning, it can produce all the ellipses possible between a circle and a straight line.

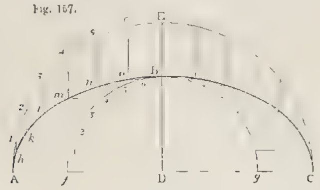
4. If in the interior of the circle of wire a regular polygon of any number of sides be inscribed, such as a decagon or dodecagon, it is evident that when the shadow of the circle becomes an ellipse, the shadows of the sides of the polygon will form a corresponding polygon, of which the angles, by reason of the parallelism of the rays of light, will always be at an equal distance from that diameter which is perpendicular to the axis of rotation. Consequently, if we trace on the plane which receives the shadows the parallels *e f*, *k a*, *m n*, *r s*, *g h*, which pass through the angles of the polygon of twelve sides, it will be found that when the frame is turned, the angles follow exactly the path of those lines.

This illustration is fertile in suggesting methods for the graphic production of the ellipse, and of figures resembling the ellipse, composed of arcs of circles. In regard to the first, let us suppose lines parallel to A B, drawn through the angles of the smaller inscribed polygon, intersecting the lines drawn through the angles of the larger polygon perpendicular to A B, and their intersections will give points in the elliptic curve. Hence—

PROBLEM LXXXV.—*To draw an ellipse when the major and minor axes are given.*

Let A C (Fig. 157) be the axis major, and D B the semi-axis minor. On A C describe the semicircle A E C, and from the same centre D, and with the length of the semi-axis minor as radius, describe the semicircle f B g. Divide

Fig. 157.



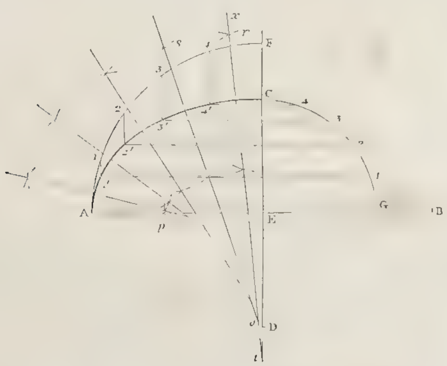
both semicircles into the same number of equal parts, 1, 2, 3, 4, &c.: through the points of division of the greater semicircle draw lines perpendicular to A C, and through the corresponding points of division of the lesser semicircle draw lines parallel to A C, and the intersections of the two sets of lines h k l m n o, &c., will be points in the curve required.

In regard to figures resembling the ellipse, composed of arcs of circles, the illustration suggests the following method of producing them graphically.

Intersect each side of the polygon by a line perpendicular to it. Continue the perpendicular from the side of the polygon nearest to the minor axis, until it intersects the continuation of the axis. Continue the next perpendicular to intersect the last, and so on, and the points of intersection so obtained become the centres from which the flat arcs are described. The intersections of the perpendiculars of the sides nearest the major axis, with the major axis, give the centres of the quicker curves.

Problem LXXXVI.—Let A B (Fig. 158) be the axis major, and C D the axis minor. On the semi-axis major,

Fig. 158.

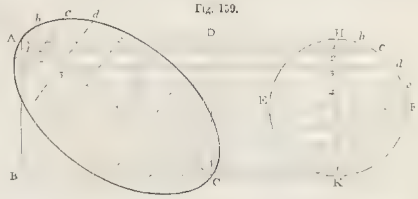


from the centre E, describe the quadrant A F, and on the semi-axis minor, from the same centre, the quadrant G C: divide each of these into the same number of equal parts, and through the divisions draw lines parallel to the two axes respectively: the intersections of these lines, 1′, 2′, 3′, 4′, indicate the angles of the polygon. Now, through the centre of the side 4′ C, draw a perpendicular cutting the minor axis produced in t, and t is the centre of the arc 4′ C. Through the centre of 3′ 4′ draw a perpendicular cutting $r\,t$ in v, and v is the centre of the arc 3′ 4′; and so on until the last arc A 1′, the centre for which is obtained at the intersection of the perpendicular with the major axis at p. As the ellipse is a symmetrical curve divided into four equal and similar parts by its axes, the remaining three quarters can readily be drawn.

The ellipse may also be considered as the section of a cylinder.

Let A B C D (Fig. 159) be the projection of a cylinder, of which the circle E H F K represents the base divided into twenty equal parts: through each division draw a line parallel to the axis of the cylinder, dividing the moiety of the surface of the cylinder A B C D into ten equal parts. Now if we imagine A B C D to be a plane corresponding

Fig. 159.

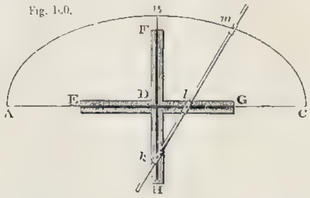


to the diameter H K, each line will be distant from it by the length of the corresponding perpendicular, 1 b, 2 c, 3 d, 4 e. Now, suppose the diagonal A C to indicate a section of the cylinder oblique to its axis, but perpendicular to the plane A B C D, the ellipse which results from that section will be traced by raising from the points where the parallels meet the line A C, the indefinite perpendiculars, and setting off upon these the distances 1 b, 2 c, 3 d, 4 e. From this is derived the most commonly used method of describing an ellipse by ordinates.

Problem LXXXVII.—*To draw an ellipse with the trammel.*

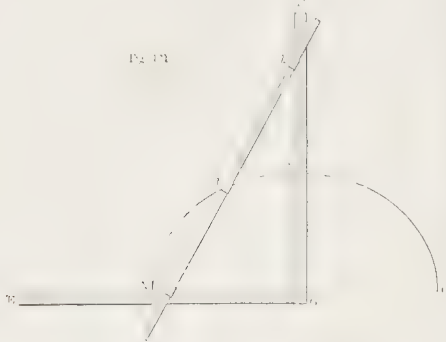
The trammel is an instrument consisting of two principal parts, the fixed part in the form of a cross E F G H

Fig. 160.



(Fig. 160), and the moveable piece or tracer k l m. The fixed piece is made of two rectangular bars or pieces of wood, of equal thickness, joined together so as to be in the same plane. On one side of the frame so formed, a groove is made, forming a right-angled cross. In the groove two studs, k and l, are fitted to slide freely, and carry attached to them the tracer k l m. The tracer is generally made to slide through a socket fixed to each stud, and provided with a screw or wedge, by which the distance apart of the studs may be regulated. The tracer has another slider m, also adjustable, which carries a pencil or point. The instrument is used as follows:—Let A C be the major, and H B the minor axis of an ellipse: lay the cross of the trammel on these lines, so that the centre lines of it may coincide with them; then adjust the sliders of the tracer, so that the distance between k and m may be equal to the semi-axis major, and the distance between l and m equal to the semi-axis minor; then by moving the bar round, the pencil in the slider will describe the ellipse.

In Fig. 161 a modification of the instrument is shown. Here a square E D F is used to form the elliptical quadrant A B instead of the cross, and the studs $h\,l\,k$ may be simply



pins, which can be kept pressed against the sides of the square while the tracer is moved. In this case the adjustment is obtained by making the distance $h\,l$ equal to the semi-axis minor, and the distance $l\,k$ equal to the semi-axis major.

PROBLEM LXXXVIII.—Fig. 162 shows an ellipse constructed on the principle of the trammel, without using that instrument. From any points, as $f\,l$ in the semi-conjugate axis B E, draw lines so intersecting the axis A C in h and n, as that $f\,h$ and $l\,n$ may be equal to the difference between the semi-transverse and semi-conjugate axes: produce these lines to g, m, and from the points l, f, &c., on the minor axis, and with the radius D C, strike the small arcs, cutting the lines in g and m. These intersections are true points in the curve. This method is obviously the same as by the trammel; and in practice it is very useful; a thin straight-edge or a piece of stiff paper being used to transfer the points at once. Thus, on the edge of the slip of paper mark off the length of the semi-axis major, $a\,b$ (Fig. 163), and then from b set off the distance $b\,c$, equal to the semi-axis minor; then by applying this to the drawing and carrying it round, keeping the points a and c one on each diameter, any number of points in the curve may be obtained.

Fig. 162.

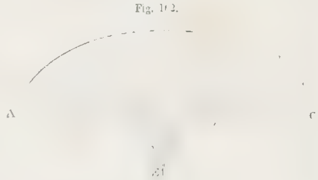
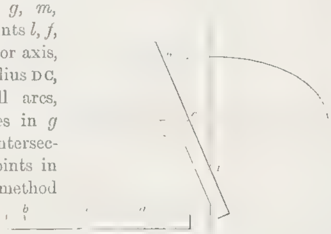


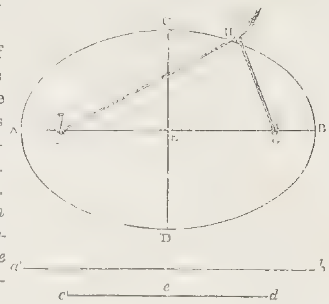
Fig. 163.



PROBLEM LXXXIX.—*An ellipse may also be described by means of a string.*

Let A B (Fig. 164) be the major axis, and D C the minor axis of the ellipse, and F G its two foci. Take a string E G F and pass it over the pins, and tie the ends together, so that when doubled it may be equal to the distance from the focus F to the end of the axis, B; then putting a pencil in the bight or doubling of the string at H and carrying it round, the curve may be traced. This is based on the well-known property of the ellipse, that the sum of any two lines drawn from the foci to any points in the circumference is the same.

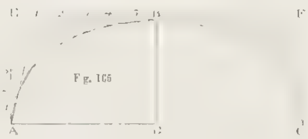
Fig. 164.



PROBLEM XC.—*The axes of an ellipse being given, to draw the curve by intersections.*

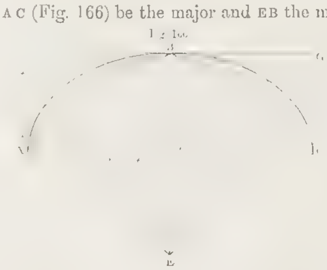
Let A C (Fig. 165) be the major, and D B the semi-axis minor. On the major axis construct the parallelogram A E F C, and make its height equal to the semi-axis minor. Divide A E and E B each into the same number of equal parts, and number the divisions from A and E respectively; then join A 1, 1 2, 2 3, &c., and their intersections will give points through which the curve may be drawn.

Fig. 165

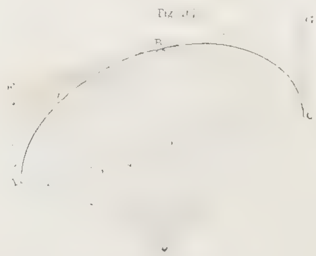


PROBLEM XCI.—*To describe an ellipse by another method of intersecting lines.*

Let A C (Fig. 166) be the major and E B the minor axis:



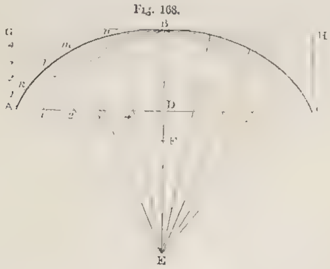
draw A F and C G each perpendicular to A C, and equal to the semi-axis minor. Divide A D, the semi-axis major, and the lines A F and C G each into the same number of equal parts, in 1, 2, 3, and 4; then from E, through the divisions 1, 2, 3 and 4, on the semi-axis major A D, draw



the lines E h, E k, E l, and E m; and from B, through the divisions 1, 2, 3, and 4 on the line A F, draw the lines 1, 2, 3, and 4 B; and the intersection of these with the

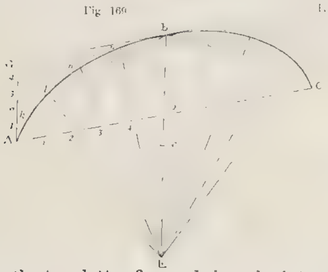
lines E 1, 2, 3, and 4, in the points *h k l m*, will be points in the curve. In the same manner are drawn the

Fig. 168.



rampant ellipse, Fig. 167, and the segment of the ellipse, Fig. 168, and the rampant segment in Fig. 169, the

Fig. 169.



point F in the two latter figures being the intersection of the major and minor axes.

PROBLEM XCII.—*To describe with a compass a figure resembling the ellipse.*

Let A B (Fig. 170) be the given axis, which divide into three equal parts at the points *f g*. From these points as centres with the radius *f* A, describe circles which intersect each other, and from the points of intersection

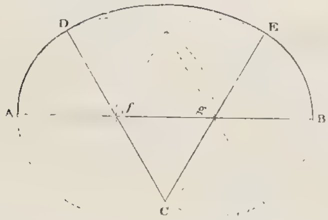


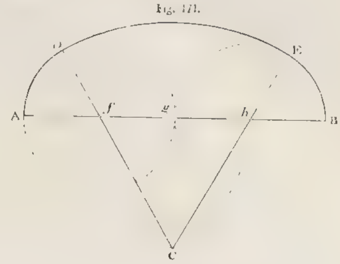
Fig. 170

through *f* and *g*, draw the diameters C *g* E, C *f* D. From C as a centre, with the radius C D, describe the arc D E, which completes the semi-ellipse. The other half of the ellipse may be completed in the same manner, as shown by the dotted lines.

PROBLEM XCIII.—*Another method of describing a figure approaching the ellipse with a compass.*

The proportions of the ellipse may be varied by altering the ratio of the divisions of the diameter, as thus:—Divide the major axis of the ellipse A B (Fig. 171), into four equal parts, in the points *f g h*. On *f h* construct an equilateral triangle *f* C *h*, and produce the sides of the triangle C *f*, C *h* indefinitely, as to D and E. Then from the centres *f* and *h*, with the radius A *f*, describe the circles A D *g*, B E *g*; and from the centre C, with the radius C D, describe the arc D E to complete the semi-ellipse. The other half may be completed in the same manner. By this method of construction the minor axis is to the major axis, as 14 to 22.

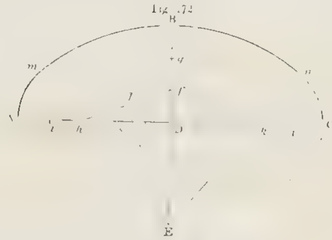
Fig. 171.



PROBLEM XCIV.—*To describe an ellipse with the compass, the transverse and conjugate diameters being given.*

Let A C (Fig. 172) be the transverse diameter, and D B the conjugate semi-diameter. Divide D B into three equal parts in *f* and *g*, and make A *h*, C *k* each equal to two of these parts: join *h f*, then from *h* and *k*, with the radius

Fig. 172.

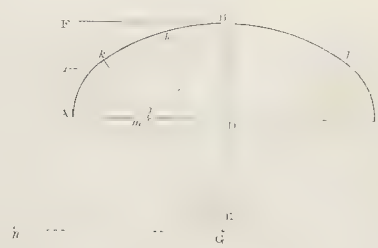


A *h*, describe the circles A *m*, C *n*. Bisect the line *h f* by the perpendicular *l*, meeting the axis B D produced in E. From E, through *h*, draw the line E *h m*, meeting the circle A *m*, and from E, with the radius E *m*, describe the arc *m* B *n*, completing the semi-ellipse.

Another Method.—The two axes of an ellipse being given, to describe the ellipse with a compass.

Let A C B E (Fig. 173) be the axes of the ellipse: draw A F parallel and equal to D B: bisect it in 1, and join 1 B. Divide A D also into two equal parts in 1, and from E,

Fig. 173.



through 1, draw the line E 1 *k*, meeting 1 B in *k*. Bisect *k* B by the perpendicular *h*, meeting the axis B E produced in G: join G *k*, cutting the transverse axis in *m*. Then from *m*, with the radius *m* A, describe the arc A *k*, and from G, with the radius G *k*, describe the arc *k* B.

PROBLEM XCV.—*The two axes* A C, B E, *being given, to describe with a compass a figure still more closely approximating to the ellipse.*

Draw A F parallel and equal to D B (Fig 174): divide it into three equal parts, and draw 1 B, 2 B. Then divide A D also into three equal parts in 1 2 D, and from E,

through the points 1 2 draw lines E m, E k, cutting the lines 1 B, 2 B, in m and k. Bisect k B by a perpendicular h, meeting E B produced in G: join k G. Bisect $m\,k$ by a perpendicular l, meeting k G in n: join $m\,n$. Then G is the centre for the arc B k, n is the centre for the arc $k\,m$,

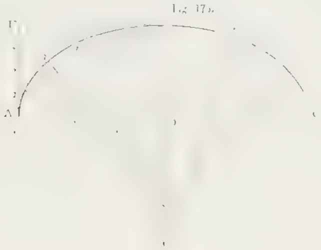
Fig. 174.

and o is the centre for the arc m A. From the centre D measure the points of intersection of the lines G k, $n\,m$, with the axis A C, and transfer the measurements to the other side of D; and set off and make G r equal to G n. Through r draw $r\,s$, and the centres G $r\,i$, for the other half of the curve, will be obtained.

PROBLEM XCVI.—*The two axes* A C, E B *being given, to describe a still nearer approximation to the ellipse with the compass.*

Draw A F (Fig. 175) parallel and equal to D B: divide it into four equal parts: divide also A D into four equal parts; and from E and B, through the divisions in D A and A F, draw lines intersecting each other in r, n, k. Bisect k B by a perpendicular h, meeting B E produced in

Fig. 175.

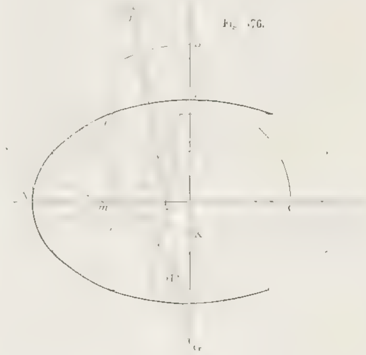


G: join G k. Bisect $n\,k$ by the perpendicular l, meeting k G in m: join $m\,n$. Bisect $r\,n$ by the perpendicular o, meeting $m\,n$ in p: join $p\,r$. Then the points G, m, p, and s will be the centres for the arcs B k, $k\,n$, $n\,r$, and r A respectively. The lines G t, $u\,y$, $w\,x$, and the point v are transferred by measurement, as before.

Note.—By dividing the lines A F and A D into a greater number of parts, a still nearer approximation to the elliptic curve will be obtained.

The ellipse being a symmetrical curve divided into four equal and similar parts by its axis, it is only necessary to obtain one of these. Thus, on the demi-axis major describe the quadrant A B (Fig. 176), and on the demi-axis minor the quadrant C D. Divide each of these into three equal parts. Through the divisions in A B draw lines parallel to the minor axis, and through the divisions in C D draw lines parallel to the major axis; and the intersections of these in $e\,f$ indicate the angles of a dodecagon of one quadrant, of which A e, $e\,f$, f D are the sides. On the middle of each of these sides raise an indefinite perpendicular. The perpendicular g G raised on f D will cut the prolongation of the minor axis in G, which will be the centre of the arc f D. The perpendicular h H raised on $e\,f$ meets the line g G in H, which will be the centre of the arc $e\,f$. The perpendicular k K raised on A e, meets

Fig. 176.

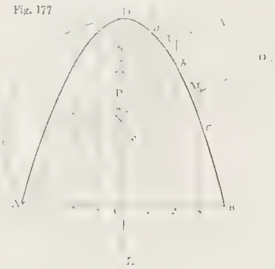


the major axis in m, which will be the centre of the arc A e. The three remaining quadrants of the ellipse are easily constructed from the data thus obtained.

THE PARABOLA.—This curve is produced by the section of a cone parallel to one of its sides. Παραβολη, its name in Greek, is given to it on account of one of its principal properties, viz., that the square of the ordinate is equal to the product of the correspondent abscissa by the parameter.

When the axis C D and double ordinates A C and C B (Fig. 177) are known, divide the axis and ordinates into the same number of equal parts, as, for example, into four. Through the points of division of the ordinates draw indefinite lines parallel to the axis; then from A draw through the divisions of the axis lines cutting the parallels in $a\,b\,c$. Then by bending a flexible ruler over these points the curve D $a\,b\,c$ B may be drawn. The other side may be done in the same manner, or it may be transferred by drawing lines parallel to the ordinates A C, C B.

Fig. 177



In order to draw perpendiculars to the curve, it is necessary to find its parameter, which is a third proportional to C D and C A. For this, draw A D and bisect it by a perpendicular, which produce until it cut the axis in F, from which as a centre, and with F D as a radius, describe the semicircle D A L, which meets the axis produced in L: C L is the parameter. Having found the parameter, to draw a perpendicular to any point M in the curve, proceed thus:—Draw through M a line M P, parallel to A B, and set off half the parameter C L from P to N, then draw N M O, which is the perpendicular sought.

In like manner, from the point R draw R S parallel to A B: make S T equal to half the parameter, and through R draw T V, which is a perpendicular to the curve at R.

PROBLEM XCVII.—*To draw a parabola by intersections.*

Let A C (Fig. 178) be the base, and D B the height of the curve. On A C construct the rectangular parallelogram A E F C, its height being equal to D B. Divide the side A E into any number of equal parts, 1 2 3 E, and the half of the base, A D, into the same number of equal parts. From these divisions raise the perpendiculars 1 *e*, 2 *f*, 3 *g*, &c., and intersect them by the lines 1 B, 2 B, 3 B, drawn from the divisions in A E to the apex of the curve B. The points of intersection *e f g*, are points in the line of the curve.

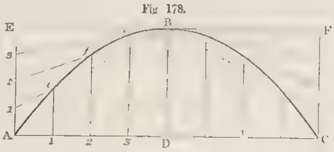


Fig. 178.

PROBLEM XCVIII.—*To draw a parabola by intersecting lines, its axis, height, and ordinates being given.*

Let A C (Figs. 179 and 180) be the ordinate, and D B the axis, and B its vertex: produce the axis to E, and make B E equal to D B: join E C, E A, and divide them each into the same number of equal parts, and number the divisions as shown on the figures. Join the corresponding divisions by the lines 1 1, 2 2, &c., and their intersections will produce the contour of the curve.

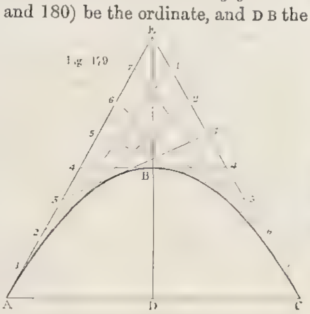


Fig. 179.

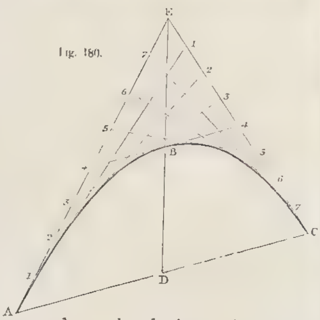


Fig. 180.

PROBLEM XCIX.—*To describe a parabola by means of a straight rule and a square, its double ordinate and abscissa being given.*

Let A C (Fig. 181) be the double ordinate, and D B the abscissa. Bisect D C in F: join B F, and draw F E perpendicular to B F, cutting the axis B D produced in E. From B set off B G equal to D E, and G will be the focus of the parabola. Make B L equal to B G, and lay the rule or straight-edge H K on L, and parallel to A C. Take a string M *r* G, equal in length to L E; attach one of its ends to a pin at G, and its other end to the end M of the square M N O. If now the square be slid along the straight-edge, and the string be pressed against its edge M N, a pencil placed in the bight at *r* will describe the curve.

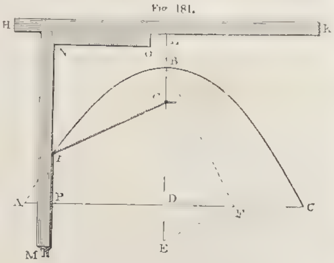


Fig. 181.

THE HYPERBOLA.—Let there be two right equal cones (Fig. 182) having the same axis, and cut by a plane M *m*, N *n*, parallel to that axis, the sections M A N, *m a n*, which result, are hyperbolas. In place of two cones opposite to each other, geometricians sometimes suppose four cones, which join on the lines E H, G B (Fig. 183), and of which the axes form two right lines, F *f*, F′ *f*′, crossing the centre C in the same plane.


Fig. 182.

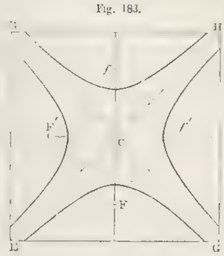


Fig. 183.

To comprehend this it is necessary to imagine two entire cones (Fig. 184) E C G, G C H, of which the angles at the summits taken together may be equal to 180 degrees, or two right angles—that is to say, the one is supplement to the other.

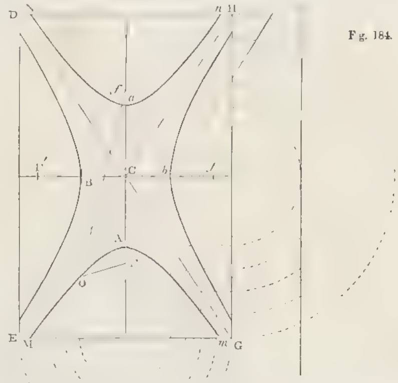


Fig. 184.

If these cones are each cut into two equal parts by sections through their axes, there will be four half cones, which being placed upon their flat and triangular surface, and disposed so that the halves of the same cone are opposite each other, as E C G to D C H and D C E to G C H, they will compose together a rectangle E D H G, of which the diagonals, E H, D G, will be formed by the sides of the demi-cones. If we now imagine these half cones cut by a plane parallel to that on which they are laid, there will result four hyperbolas, which are called conjugate. A *a* will be the first axis of the opposite hyperbolas, M A *m*, N *a n*, and B *b*, the second axis; but if we consider the two other hyperbolas, B *b* will be their first, A *a* their second axis. The diagonals, E C H, D C G, which represent the sides of the cones, are called the asymptotes, and the point C the centre. When the axes A *a* and B *b* are equal, as in Fig. 183, the asymptotes form right angles, and the

four hyperbolas are termed equilateral or circular; because, if from the centre C a circle is described, it will touch the summits of the four hyperbolas, which will be alike. But if the angles are unequal, as in Fig. 184, the curve which shall touch the summits must be an ellipse, wherefore such hyperbolas are sometimes denominated elliptic hyperbolas.

Hyperbolas have a focus, which is thus found:—Take A *b* (Fig. 184) equal to C *f*, and set it from C to F, F′, *f*, *f*′, then F, F′, *f*, *f*′, are the foci, which, whether the hyperbolas are circular or elliptic, are always equidistant from the centre C.

The property of the foci is, that if a line be drawn from any point of a hyperbola to its focus, and another line from the same point to the focus of the opposite hyperbola on the same axis, then the difference of these two lines will be always equal to the axis, on the production of which the foci are. Thus, if a line O F (Fig. 184) be drawn from a point in the hyperbola to its focus F, and another line from the same point to the focus of the opposite hyperbola *f*, then O *f* — O F = the axis A *a*.

This property furnishes a ready mode of describing the hyperbola graphically.

The first axis of any two hyperbolas A *a* (Fig. 185), and their foci F *f* being known, to find any number of points in the curves. On the indefinite line E G (Fig. 186) make the point E H equal to A *a* in Fig. 185: then from the foci, with a radius greater than A *f* or F *a*, describe the indefinite arcs *e e*: then set off this radius on the line E G (Fig. 186), from E to 1, and take the difference H 1, and with that as a radius from the foci, describe other arcs (Fig. 185) cutting the first arcs in 1 1, which will be points in the hyperbolas. In the same way take a radius E 2, and describe arcs from the foci as centres, and intersect them with other arcs having a radius equal to H 2, and so on for the points 3, 4. The intersections are points in the curve through which the hyperbola may be drawn.

Fig. 185.

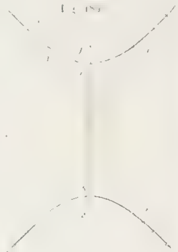
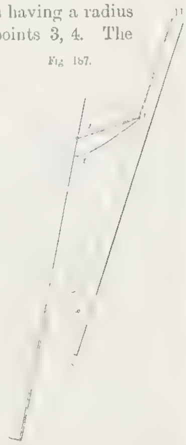


Fig. 186.

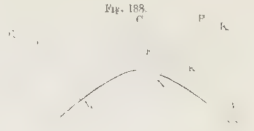
The hyperbola can also be described by a continuous motion. Let H K (Fig. 187) be a rule, one end of which moves round the focus F as a centre. To its other end let there be attached a thread a little shorter than the length of the rule, and let the other end of the thread be fastened to the focus *f* of the hyperbola to be described. When the rule is in the line of the axis F *a*, the length of the cord or thread shall be such that the double *b* fall upon the summit of the hyperbola *a*. Then making the rule move round F as a centre, and at the same time holding the double of the line close to the rule by a pencil or tracer, the pencil will describe a hyperbola.

Fig. 187.



To draw tangents and perpendiculars to the hyperbola, of which the asymptotes are known. From the points from which it is required to draw the perpendiculars M N (Fig. 188), draw the lines H M, K N parallel to the asymptotes, and make A H equal to H C, and B K equal to K C. Then the line A M E is a tangent to the curve at the point M, and the line B N F is a tangent to the curve at the point N; and if from these points lines be drawn M O, N P, perpendiculars to the tangents, these lines will also be perpendiculars to the curve.

Fig. 188.



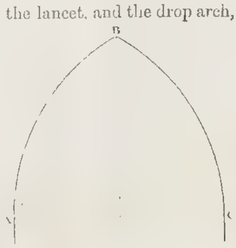
PROBLEM C.—*The axis, vertex, and ordinate of a hyperbola being given, to find points in the curve.*

Let D A (Figs. 189, 190, 191) be the ordinates, D B the height or abscissa, and D E the axis. The letters of reference are the same in all the figures. Through B draw F G parallel to A C, and through A and C draw A F, C G, parallel to D E: divide A D, A F into the same number of equal parts. From E draw lines to the divisions in A D, and from B draw lines to the divisions in A F, and the intersections of the lines from the corresponding points will give points in the curve.

CONSTRUCTION OF GOTHIC ARCHES.

These are the equilateral, the lancet, and the drop arch, drawn from two centres; and the four-centred and ogee arch, drawn from four centres.

THE EQUILATERAL ARCH.—This arch is constructed on the equilateral triangle A B C (Fig. 192), C and A being respectively the centres of the arcs A B, C B.



THE LANCET ARCH.—Bisect the width A B (Fig. 193) in C, and produce A B indefinitely to D and E: from A and B, with the radius A C, describe semicircles cutting A B in D and E, the centres from which the arcs are to be described.

Fig. 193.

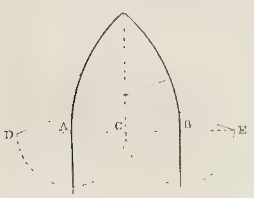
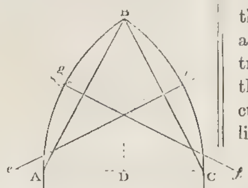
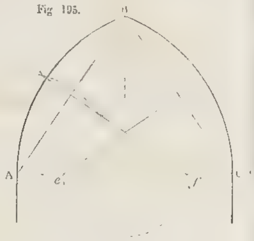


Fig. 194.



Let A C (Fig. 194) be the width and D B the height of the arch. Join A B, C B, and bisect the lines A B, C B, and draw through the points of bisection the perpendiculars *g f* and *h e*, meeting the line A C produced in *e* and *f*. From the points *e* and *f*, with the radius *f* A or *e* C, describe the arcs A *g* B, C *h* B.

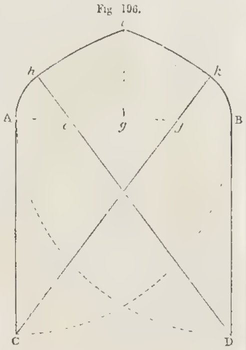
Fig. 195.



THE DROP ARCH.—Join A B (Fig. 195) and C B as before, and bisect them; and through the points of bisection draw perpendiculars, cutting A C in *e* and *f*, which two points are the centres of the arcs A B, B C.

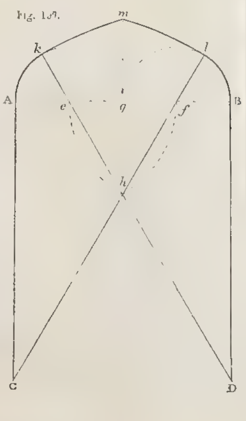
THE FOUR-CENTRED ARCH.—*To describe a four-centred Gothic arch.*—Divide the width of the arch A B (Fig. 196) into four equal parts, in *e*, *g*, *f*. Draw A C, B D perpendicular to A B, and from the points A and B, with the radius A B, describe the arcs A D, B C. Join D *e*, C *f*, and produce the lines to *h* and *k*. Then the points *e* and *f* are the centres of the arcs A *h*, B *k*, and the points C and D of the arcs *h l*, *k l*. The height of the arch in this example is $\frac{2}{5}$ths of its span.

Fig. 196.



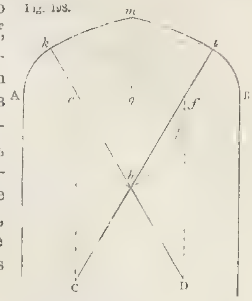
Another method, producing a flatter arch.—Divide A B (Fig. 197) into four equal parts, in *e*, *g*, *f*, and draw the perpendiculars A C, B D: from the points *e* and *f*, with the radius *e f*, describe the arcs *e h*, *f h* intersecting at *h*, and through the point of intersection draw *e h*, *f h*, and produce the lines both ways to *k* and D, and *l* and C respectively. Then from the points *e* and *f*, with the radius *e* A, describe the arcs A *k*, B *l*; and from the points C and D, with the radius C *l*, describe the arcs *l m*, *k m*. The height of the arch is $\frac{3}{8}$ths of its span.

Fig. 197.



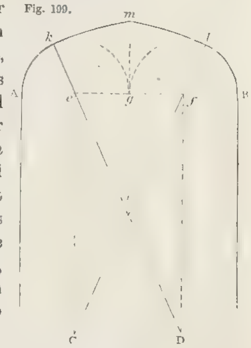
In Fig. 198 the centres of the arcs A *k*, B *l* are found as before, by dividing A B into four equal parts, in *e*, *g*, *f*, and letting fall the perpendiculars in this case, not from the extremities of the line A B as before, but from the centres *e* and *f*. From these, then, let fall the perpendiculars *e* C, *f* D, to meet the lines *e h* and *f h* produced, when C and D become the centres of the arcs *k m*, *l m*.

Fig. 198.



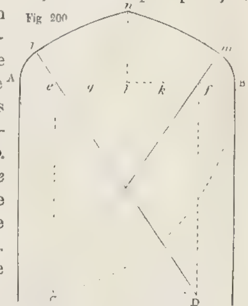
The arch (Fig. 199) is still flatter than the last. The line A B is divided into four equal parts in *e*, *g*, *f*; then from the centres A and B, with the radius A *f*, the arcs *e h*, *f h* are described, and through the point of their intersection the lines *e h*, *f h* are drawn and produced until they meet perpendiculars let fall from *e* and *f*. The arcs A *k*, B *l* are described from *e* and *f*, with the radius A *e*, and the arcs *k m*, *l m* from D C, with the radius D *k*. The height is $\frac{1}{3}$d of the span.

Fig. 199.



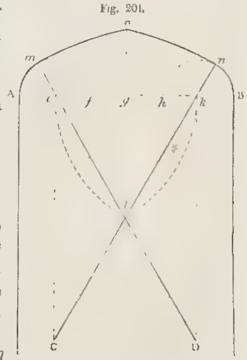
Divide the line A B (Fig. 200) into six equal parts, in the points *e*, *g*, *h*, *k*, *f*. From *e* and *f* let fall the perpendiculars *e* C, *f* D: from the points A and B, with the radius A B, describe the arcs B C, A D cutting the perpendiculars *e* C, *f* D in C and D. Draw D *e l*, C *f m*. Then *e* and *f* are the centres of the arcs A *l*, B *m*, and C and D the centres of the arcs *m n*, *l n*. The height of the arch is, like the last, $\frac{1}{3}$d of the span.

Fig. 200.



To make the crown of the arch flatter than in the last figure, proceed as before for the centres of the haunch arches, by dividing A B (Fig. 201) into six parts, in *e*, *f*, *g*, *h*, *k*: draw A *m*, B *n*; then from the centres of these arches *e k*, with the distance between them as radius, describe the arcs *e l*, *k l*, and through *l* draw the lines *e l*, *k l* produced to meet the perpendiculars let fall from *e* and *k*, in C D. Then the points C and D are the centres of the arcs *m o*, *n o*.

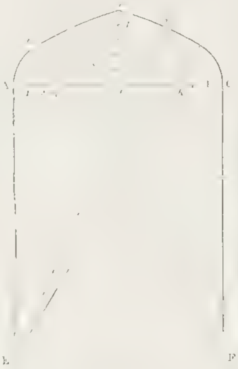
Fig. 201.



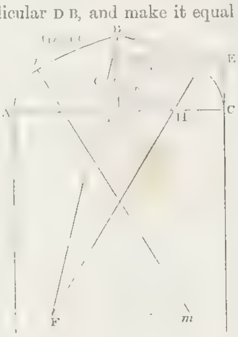
To draw a four-centred arch when the height, width, or span are given.—Let A C (Fig. 202) be the span of the arch, and D B its height.

Divide D B into five equal parts, in 1, 2, 3, *g*, B, and set off on the line A C, from A and C, three of those parts to A *h*, C *k*. Then from the point *g*, with the radius *g h*, describe the arc *n h k o*, and from the points *h k*, with the radius A *h* or C *k*, describe the arcs A *n*, C *o*. From the intersections of these arcs with the arc *n h k o*, and through the centres *h k*, draw *n h* F, *o k* E. Then bisect *n* B, *o* B in *l* and *m*, and produce the lines until they meet *n h* F and *o k* E in F and E, which two last points are the centres of the arcs *n* B, *o* B.

Fig. 202.



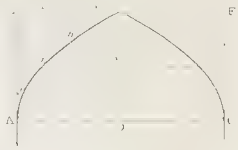
Another Method.—Bisect the width of the arch A C (Fig. 203) in D, draw the perpendicular D B, and make it equal to the height of the arch. Divide it into three equal parts: through the second division draw 2 E parallel to A C, intersecting the line C E drawn from C perpendicular to A C in E. Join E B, and draw from B the line B G F at right angles to it. On C A set off C H equal to D 2; and on B F set off B G equal also to D 2: join G H, and bisect it at *n*. From the point F, where the bisecting line meets B G F, draw F H *k*. Then H will be the centre of the arc C *k*, and F the centre of the arc *k* B. For the other side of the arch, draw F *m* parallel to A C; and from the centre line B D produced, set off *m* equal to F: draw *m l*.



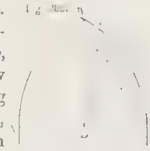
Another Method.—Divide the height D B (Fig. 204) into two equal parts, and draw 1 E parallel to A C, and meeting the perpendicular C E in E. Join B E, and draw B F at right angles to it: set off from C and B the points H and G, equal to D 1. Join H G, and bisect the line in *k*. The point F, in which the bisecting line of G H cuts B F, is the centre of the larger arc *l* B, and H is the centre of the smaller arc C *l*.

To describe a Gothic arch by the intersection of straight lines, when the span and height are given.—Bisect A C (Fig. 205) in D, and from the point D and the extremities of the line draw A E, D B, C F at right angles to A C, and each equal to the height of the arch: join E B, B F. Divide the line D B into any number of equal parts, 1, 2, 3, B, and through the divisions draw lines parallel to A C. Divide the line E B, B F into the same number of equal parts, and from A and C draw lines A 1, A 2, A 3; and their intersection with the horizontal lines in *f*, *g*, *h*, will be points in the curve required.

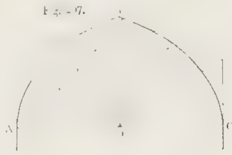
Fig. 205.



To draw the arches of Gothic groins, to mitre truly with a given arch of any form.—Let A C (Fig. 206) be the width of body range, and B D its height. Join C B, and divide it into any number of equal parts: from the centre D, through the points of division, draw straight lines D 1, D 2, D 3, D 4, meeting the circumference of the arch in *l*, *m*, *n*, *o*. From B, through these points in the circumference, draw B *o*, B *n*, B *m*, B *l*, and produce them to meet a perpendicular raised from C.



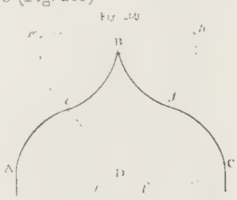
Let A C (Fig. 207) be the width of the groin arch, and D B its height. Join A B, and divide it into the same number of parts as C B in Fig. 206; and draw through the points 1, 2, 3, 4 the lines D 1, D 2, D 3, D 4. Then from A draw a line perpendicular to A C, and transfer to it the divisions from the corresponding line in Fig. 206; and from these divisions draw lines to B. The intersection of these lines with the lines D 1, D 2, &c., will give points through which the curve may be traced.



To draw an ogee arch.—Divide the width A B (Fig. 208) into four equal parts, in *d*, *c*, *e*; and on *d*, *e* erect the square *d*, *f*, *g*, *e*. The points *d*, *e*, *f*, *g*, are the centres of the four quadrants A *k*, *k l*, B *h*, *h l*, composing the arch.

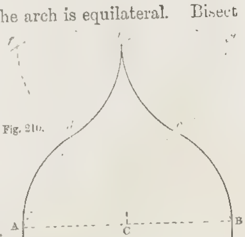
Fig. 208.

Another Method.—Let A C (Fig. 209) be the width and D B the height of the arch. Join A B, B C, and bisect the lines in *e*, *f*; then from the centres A, *e*, B, *f*, C, with the radius A *e* or *e* B, describe the arcs intersecting in the points *g*, *h*, *k*, *l*, which are the centres of the four arcs composing the ogee arch.



Another Method, when the arch is equilateral. Bisect A B (Fig. 210) in C, join A *h*, B *h*. From C, with the radius A or B, describe the arcs A *d*, B *e*; then, to find the centres of the other arcs, from the points *d*, *e*, and *h* as centres, and with the same radius as before, describe arcs intersecting each other in the points *f* and *g*, which are the centres of the arcs *h d*, *h e*.

Fig. 210.



PART SECOND.

CONSTRUCTION AND USE OF DRAWING INSTRUMENTS.

Before proceeding to introduce the student to stereography, it is proper to describe the instruments used by the architectural draughtsman, and to explain their construction and application.

Cases of drawing instruments generally contain compasses of various kinds, scales, protractors, parallel rulers, and drawing pens. Each of these shall be described in order.

Compasses

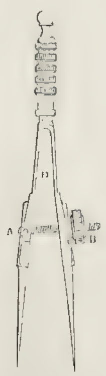
These are of different kinds, viz :—dividers, compasses with moveable legs, bow-compasses, directors, proportional-compasses, and beam compasses.

Dividers.—These are used for taking off and transferring measurements. The common dividers are moderately-sized compasses, without moveable legs, working somewhat stiffly in the joint, and having fine, well-tempered points of equal length, lying fairly upon each other when closed. When dimensions are to be taken with extreme accuracy, these dividers will not, under the most skilful manipulation, work with the delicacy and certainty that are required. In such cases, the draughtsman resorts to his *hair* dividers: these are compasses in which one leg is acted upon by a spring; and a finely-threaded screw, pressing upon this spring, changes the direction of the point to the nicety of a hair's-breadth. The distance to be measured is first taken as accurately as possible between the points of the compasses, and the screw is then turned until the dimension is obtained with positive exactness. This instrument is useless unless it be of the very best quality: it must work firmly and steadily; and the points need to be exquisitely adjusted, exceedingly fine, and well-tempered.

Instruction for using dividers, which are applied only to measure and transfer distances and dimensions, may appear superfluous; but there are a few simple directions which may save the young draughtsman much perplexity and loss of time. It is, of course, desirable to work the compasses in such a manner that, when the dimension is taken, it may suffer no disturbance in its transfer from the scale to the drawing. In order to this, the instrument is to be held by the head or joint, the forefinger resting on the top of the joint, and the thumb and second finger on either side. When held in this way, there is no pressure except on the head and centre, and the dimension between the points cannot be altered; but, if the instrument be clumsily seized by a thumb on one leg, and two fingers on the other, the pressure, in the act of transference, must inevitably contract, in some small degree, the opening of the compasses; and if the dimension has to be set off several times, the probability is, that no two transfers will be exactly the same. And, whilst it is all-important to keep the dimension exact, it is also desirable to manipulate in such a way, when setting off the same dimension a number of times, that the point of position be never lost. Persons unaccustomed to the use of compasses, are very apt to turn them over and over in the *same* direction, when laying down a number of equal measures, and this necessitates a frequent change of the finger and thumb, which direct the movement of the instrument: the consequence is, either that the fixed leg is driven deep into the drawing, or it loses position. Now, if the movement be alternately above and below the line on which the distances are being set off, the compasses can be worked with great freedom and delicacy, and without any liability to shifting. If a straight line is drawn, and semicircles be described alternately above and below the line, it will show the path of the traversing foot. If the two movements are tried, the superiority of the one recommended will at once be discovered. The forefinger rests gently on the head; and the thumb and second finger, without changing from side to side, direct the movement for setting off any number of times that may be required. Before applying the dividers to the paper, they should be opened wider than the required distance: the point of the near leg is then to be put gently down on the paper, the leg resting against the thumb, and the other leg gently brought to the required distance. The pressure is thus resisted by the thumb, and there is no risk of making a hole in the paper. This remark applies to the use of compasses of all kinds.

There is a third sort of dividers, named the Spring Compasses, in which steadiness is combined with the delicacy of adjustment of the hair compasses. The last-named are liable to error, in consequence of the weakness of the spring leg; and without very careful handling, the dimension, though taken with extreme exactness, cannot be laid down correctly. Now, the spring compasses, of which we annex a figure (Fig. 211), have, from their principle of construction, a steadiness and firmness which cannot be surpassed. The legs are fixed to a steel-spring D, whose elasticity keeps the points extended: the screw A B is fastened by a pivot-joint, and passes through a slot at B, and the opening of the instrument is adjusted by a nut working upon the fine thread of the screw. The legs are jointed below the screw; and the required dimension can therefore be taken between the points *nearly*, and afterwards more accurately determined by a gentle turn of the nut. The instrument is worked by the forefinger and thumb on the head; and, in setting off, the alternate motion before-mentioned is to be observed. The figure gives the exact size of an instrument suitable for small dimensions; but the draughtsman ought to provide himself with a variety of sizes, which will take in all the dimensions he may ordinarily require. And the advantage of having several of these instruments is, that dimensions which occur frequently in a drawing, can be left in one or more of them undisturbed; and thus much

Fig. 211.



of the time saved that would otherwise be occupied in re-adjustment. When purchasing spring compasses, the young draughtsman must select only those in which the screw works on a pivot, since, if it be fixed immoveably at A, it cannot adapt itself to the various extensions of the legs, and the fine thread is then much injured by the unequal pressure of the nut.

Compasses with Moveable Legs.—Every case of instruments is provided with a pair of compasses, of which one leg is moveable, and may be substituted by others carrying a pen or pencil. This instrument serves, in the first instance, as a divider; and the additional legs enable the draughtsman to describe arcs and circles temporarily in pencil, or permanently in ink. As it is an object to effect the change of leg with little loss of time, some attention must be paid, when selecting the drawing-case, to the contrivance for removing and securing the legs with despatch. The worst construction is that wherein the leg is secured by a screw, since it involves a tedious process of fixing and unfixing; and the best is, perhaps, the bayonet mode of inserting the leg, which is effected in an instant, and makes a firm junction. In working with the pencil and pen legs, it is desirable to keep them vertical to the drawing; and indeed, with the last, it is absolutely necessary, as otherwise the arc or circle would be described with the side of the pen, and either it would not mark at all, or would produce a ragged, unsightly line. These legs are therefore jointed, so that, in proportion as the compasses are extended, they may be bent inward, and brought to a vertical position. But this adaptation unfits the instrument to describe arcs and circles of very small radii; for the moveable leg has usually a little additional length to compensate for the bending of the joint, and this prevents a steady adjustment when the points of the compasses are brought near together. In return for this restriction, however, we have a contrivance for describing arcs and circles of larger radii than fall within the usual range of the instrument. It is found, on trial, that if we attempt to describe an arc of more than a certain radius with the pen-leg, we require to throw the other leg into a very oblique position, with the almost certainty of losing its place, and making a false permanent line. To meet this difficulty, a brass *lengthening bar* is provided, which receives the pen-leg in the one end, and joins to the compasses, by a bayonet-fixing, at the other. When thus lengthened, the instrument will command a radius of six or eight inches with ease and security.

The pencil-leg consists of a tube split through half its length, with a ring to move up and down, by which a small short pencil is fixed much on the same principle as the chalk in a portcrayon. The pen-leg is formed of two blades of steel, terminating in thin, rounded, and well-adjusted points. A spring is inserted between the blades, to separate them; and they are brought together by a screw which passes through them, and which is capable of adjusting the pen for a strong line, or for one as fine as a hair. In using this leg, the screw is slackened, and ink inserted between the blades with a quill-pen, or a camel-hair pencil, according to the nature of the colouring fluid used; and the blades are then brought gradually together, until they will produce a line of the desired quality. The draughtsman will, of course, try the line on his waste-paper before he ventures to describe it on his drawing. A third moveable leg, named the Dotting Pen, is sometimes included in the drawing-case, and though it is an instrument rather uncertain in its performance, some draughtsmen manage to employ it with very good effect in the drawing of dotted lines. It is jointed in the same manner as the pen and pencil legs, and consists of two blades terminating in a small revolving wheel E (Fig. 212), which is retained in its position by the screw D. The one wheel might, of course, be permanently fixed, but usually there are several given with the pen, to produce dots of greater or less strength; the contrivance of the screw, therefore, admits the ready substitution of one wheel for another. When this pen is used, ink must be inserted between the blades over the wheel; and the latter should be run several times over the waste-paper, until, by its revolution, it takes the ink freely, and leaves a regularly dotted line in its course. It must be admitted that, with every care, it sometimes fails in its duty, and leaves blank spaces; but where much straight or curved dotted line is required, it will very much abridge the draughtsman's labour; and, if it performs well, will dot with far greater regularity than the steadiest hand.

Fig. 212.

The compasses with moveable legs have frequently to describe an entire circle, and an inexperienced hand finds some difficulty in carrying the traversing leg neatly round the circumference without the other leg losing position. Some persons have recommended the movement of the dividers, that is, to form half the circle in one direction, and half in a reverse direction; and this may answer very well with the pencil-leg, but not with the pen leg; since it is almost impossible, in the latter case, to unite the two semicircles without leaving marks of junction, which very much injure the continuity of the line that forms the circle. This being the case, it is preferable to adopt a method that shall answer equally well with either leg, and which, by one continued sweep, shall complete the figure. It is very desirable to use compasses for circles that have a due relation to the radii of the circles to be described; that is to say, such as will allow both the revolving and fixed leg to be nearly vertical to the paper; for if the fixed leg is inclined obliquely, it is very apt to lose position, or to work a large unsightly hole in the drawing. When the compasses are so adjusted that both legs are vertical, or very nearly so, it is at once a simple and elegant movement that carries the traversing point round the circle. Let the forefinger rest on the head, and the thumb and second finger on the sides; commencing the sweep at the top, and towards the right hand: the second finger becomes disengaged when a quadrant is described, and the forefinger then winds the head along the inner part of the thumb, until the point has performed the entire circuit. It is not always desirable to commence the circle at the top, but more frequently from a point which it is to touch accurately: this, however, presents no difficulty that the method of sweeping does not meet. The only thing necessary is to place the fingers and instrument in position, in the first instance, with reference to the starting point; and this is readily done by a slight bending of the wrist. To one familiar with the use of instruments, these instructions for manipulation may appear unnecessarily minute; but if he will place his compasses for the first

time in the hands of a youth, and observe his lack of intuitive dexterity, he will admit that they are in no degree too minute for a tyro.

Bow Compasses.—In every case of instruments, making any pretensions to completeness, there is one pair of Bow Compasses; but we shall advert to several kinds, each recommended by a peculiar excellence or adaptation to the draughtsman's purposes. This instrument may be described, generally, as small compasses suited for describing arcs and circles of short radii, and which can be worked with great facility by the finger and thumb. The most ordinary construction, and that usually found in the drawing-case, has the legs, one of which is a pen, moving freely on a joint, and terminating at the top in a small handle. The pen-blades are a little longer than the other leg, in order that the latter may keep its vertical position throughout a sweep, and not lose its centre. The performance of this small instrument is very satisfactory; a succession of small arcs and circles may be described rapidly and delicately, without leaving the centres strongly marked by the fixed point; and this contributes much to the beauty of a drawing, since nothing is more offensive than to see the paper studded with small holes exposing every insertion of the compasses.

The annexed engraving (Fig. 213) shows an improvement of the instrument. The vertical position of the pen-leg is secured by the joint C; the blades B are closed by the screw F, which, according as it is tightened or relaxed, renders the line finer or stronger at pleasure; and the box-screw A unites the legs and handle firmly. The leg A D has a socket at its extremity, to admit a steel needle, which is fastened by a clamp E. This last contrivance is simple but valuable. The fine point of the compasses is soon destroyed by continued use, and to renew it by grinding reduces the length of the leg, and in course of time renders the instrument worthless; whereas, a fresh needle can be introduced into the socket as often as is necessary, and a constant delicacy of point maintained.

Fig 213.

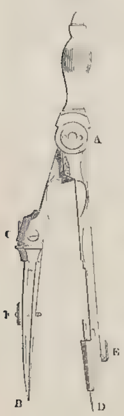
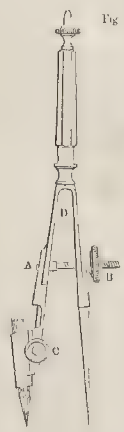


Fig 214.

Fig 215.

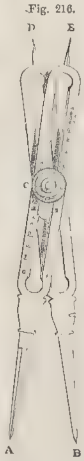


Bow compasses can also be had carrying a pencil-leg. They differ from those previously described only in having a holder for the reception of a thin short pencil, which is held tight by the screw F (Fig. 214). These have also the joint C, the needle-point E, and box-screw joint A. Bows to carry a pencil are seldom included in the drawing-case; but they, and indeed all, of the other instruments, can be purchased separately. The pencil-leg is certainly a very useful aid to the draughtsman, since there are many occasions where it is desirable to get all the parts of a drawing inserted with the lead, before making them permanent; and arcs and circles of small radii are not readily described with the larger compasses, supposing them to be properly adapted for sweeping curves of greater magnitude.

Another sort of Bows, named Spring Bow-Compasses (Fig. 215), though limited in their application to small curves and circles, are very delicate and exact instruments, so far as their range extends. They are in principle identical with the Spring Dividers, which we have already described, and one leg is provided with a holder for a pencil or pen. The advantages of this construction can be appreciated only by those who know the difficulty of securing a small radius, with perfect exactness, by compasses that are extended and closed in the ordinary manner; and who have experienced the mortification of seeing an otherwise fine drawing marred and disfigured by small curves or circles, described with a radius deviating from truth in an error of perhaps not more than a hair-breadth, yet failing in one instance to reach the point of junction, and in another passing beyond it.

Directors, or Triangular Compasses.—This instrument is used for taking three angular points at once, or for laying down correctly a third point with relation to other two. One form of construction is that of an ordinary pair of compasses, with an additional leg attached by a universal joint; and another contrivance, much recommended for simplicity and facility in its use, is a solid plate of three arms, each arm carrying a moveable limb, into which a short pointed needle is inserted at right angles. In using the first, the compasses are opened, and two points taken, and the additional leg is extended in any direction to take up the third point; the management of the second is equally easy, the needle-points are successively adjusted to the angles by the flexure of the moveable limbs. With either instrument, the draughtsman is saved the tedious process of constructing triangles, and determining the relative position of neighbouring points in his drawing.

Fig. 216.



Proportional Compasses.—These are used for the enlargement or reduction of drawings. The simplest form is that named *wholes and halves*, which may be described as two bars pointed at each extremity, and working transversely on a box-screw joint, and forming, as it were, two compasses, the legs of the one being twice the length of those of the other. If any distance be taken between the points of the longer legs, half that distance will be contained at the other end. The application of the instrument to the reducing or enlarging any drawing one-half, is sufficiently obvious. The proportional compasses, properly so called, is a more complicated contrivance, and admits of more varied application. Its form and general construction are seen in the annexed engraving (Fig. 216). It is in principle the same as the wholes-and-halves, with this difference, that the screw-joint C passes through slides

moving in the slots of the bars, and admits of the centre being adjusted for various relative proportions between the openings A B and D E. Different sets of numbers are engraved on the outer faces of the bars, and by these the required proportions are obtained. The instrument must be closed for adjustment, and the nut C loosened; the slide is then moved in the groove, until a mark across it, named the index, coincides with the number required; which done, the nut is tightened again.

The scales usually engraved on these compasses are named Lines, Circles, Planes, and Solids.

The scale of lines is numbered from 1 to 10, and the index of the slide being brought to any one of these divisions, the distance D E will measure A B in that proportion. Thus, if the index be set to 4, D E will be contained four times in A B.

The line of circles extends from 1 to 20; and if the index be set to 10, D E will be the tenth part of the circumference of the circle, whose radius is A B.

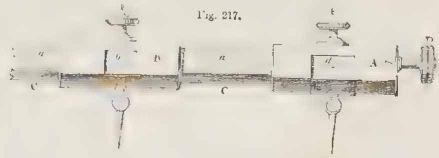
The line of planes, or squares, determines the proportion of similar areas. Thus, if the index is placed at 3, and the side of any one square be taken by A B from a scale of equal parts, D E will be the side of another square of one-third the area. And if any number be brought to the index, and the same number be taken by A B from a scale of equal parts, D E will be the square root of that number. And in this latter case, D E will also be a mean proportional between any two numbers, whose product is equal to A B.

The line of solids expresses the proportion between cubes and spheres. Thus, if the index be set at 2, and the diameter of a sphere, or the side of a cube, be taken from a scale of equal parts by A B, then will D E be a diameter of a sphere or side of a cube of half the solidity. And if the slide be set to 8, and the same number be taken from a scale of equal parts, then will D E measure 2 on the same scale, or the cube root of 8.

The scale of lines and that of circles are those of most value to the draughtsman. The first enables him to reduce or enlarge in any required proportion; and the second gives him the side of the square or polygon, that can be inscribed in a given circle. The instrument needs to be used carefully, since its accuracy depends on the preservation of the points. If both or either of these are broken, or diminished in length, the proportions cease to be true. In place of using the proportional compasses in setting off a number of times, which would soon wear the points, rather take the distance in the Dividers.

Beam Compasses.—The draughtsman has frequently to measure and lay down distances, and to sweep with radii, which the ordinary instruments cannot reach. In these cases, and when extreme accuracy is necessary, he resorts to the Beam Compasses, which are usually made of well-seasoned mahogany, with a slip of holly or box-wood on the face, to carry the scale. Two brass boxes with points are fitted to the beam, one of which moves freely to take in any required distance, and the other is connected with a slow-motion screw working in the end of the beam, and can thus be adjusted with extreme delicacy to any measure or radius. Reading-plates, on the Vernier principle, subdivide the divisions of the scale on the beam, and by them any measure to three places of figures is taken with extreme truth. Referring to Fig. 217, we proceed to describe it more particularly. C C is the mahogany beam, whose length may be taken at pleasure, although it is not advisable to extend it beyond four or five feet, lest it bend by its own

Fig. 217.



weight: *a a* is the strip of holly or box-wood on which the scale is engraved: B is the brass box, which moves freely along the beam, and is secured in position by the clamp-screw F: A is the other brass box, made fast to the slow-motion screw D, which works in the end of the beam, and winds it into or out of the box A, to obtain perfect adjustment; and *d b* are the Vernier scales, or reading-plates. The mahogany beam is sometimes substituted by a brass tube.

Before describing the method of setting the instrument, we must explain, in few words, the nature of a Vernier scale. Take any primary division of a scale, and divide it into ten parts, then take eleven such parts and divide the line which they form into tenths likewise; this last then becomes a Vernier or reading-scale. The primary division is 100, its subdivision 10, and the excess of the Vernier division 1; so that if the scale and Vernier are placed parallel and close to each other, a distance or measure may be read accurately to the unit of three places of figures. We illustrate by a diagram (Fig. 218), which shows the Vernier attached to the scale *a b* of the ordinary barometer.

Fig. 218.

Here *a b* is divided into inches and tenths of inches; and *c d* is the Vernier, consisting of eleven subdivisions of *a b*, divided into tenths. Now the *zero*, or commencement of notation, on the Vernier is, in this case, adjusted to 30 inches on the scale; and its division 10 coincides with 28 inches 9 tenths; hence every division of the Vernier is seen to be one and one-tenth of the scale divisions. To read off, therefore, the hundredths of an inch that the zero of the Vernier may be in advance of a tenth, observe what division of the Vernier coincides most nearly with any division of the scale, and that will indicate the hundredths. Thus, taking the adjustment of the figure, the zero corresponds exactly with 30 on the scale, and its division 10, with 28 and 9 tenths; and we therefore read 30 inches. But if the zero were so posited between 29 and 9 tenths and 30, that the 8 of the Vernier should correspond exactly with a tenth of the scale, we should read 29 inches, 9 tenths, and 8 hundredths. And this is evident, for if zero be 8 hundredths in excess of a tenth, it is only the eighth division of the Vernier that will be found to coincide exactly with a tenth of the scale.

To adjust the beam compasses for a distance or radius of 13 inches, 5 tenths, 3 hundredths, the box A is to be moved by the screw D until the zero of the Vernier corresponds with the zero of the beam, and is then to be secured in position by the clamp E: this done, the box B is slid along the beam until the zero of *its* Vernier coincides with 13 inches 5 tenths: lastly, the box B is moved

by the slow-motion screw, and the third division of the Vernier brought to correspond with the third tenth of the scale, which consequently adds 3 hundredths to the distance or radius previously taken. The point of the slide or box F can be removed, and a pen or pencil substituted with accurate adjustment. The beam compasses are seldom employed, except when extreme accuracy is necessary. On many occasions, curves of long radius are drawn by means of slips of wood, one edge of which is cut to the required circle.

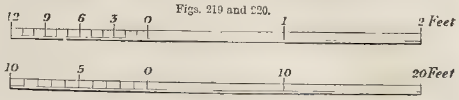
Having described the various sorts of compasses in ordinary use, it is unnecessary to do more than advert briefly to some modifications and improvements in form and detail. It has been thought an advantage to joint both legs of the instrument, in order to bring them to a vertical position at any extension; but this is a doubtful advantage, especially in compasses designed for drawing arcs and circles, since each leg being equally removed from the centre of motion, there must be a tendency on the part of the one fixed, to *tear* away from its position. Mr. Brunel has introduced what are called Tubular Compasses, in which the upper part of the legs lengthens out like the slide of a telescope, thus giving greater extent of radius when required. The moveable legs are double, having points at one end, and a pencil or pen at the other; and they move on pivots, so that the pen or pencil can be instantly substituted for the points, or *vice versa*, and that with the certainty of a perfect adjustment. The design is very ingenious, and offers many conveniences, but the instrument is too delicate for ordinary hands. Without extreme care, it must soon be disarranged and rendered useless. The Portable or Turn-in Compasses, is a contrivance which combines dividers, compasses with moveable legs, and bows, in a pocket instrument, folding up to a length of not more than three inches. The upper legs are hollow, and admit either leg of the pen and pencil bows, which can therefore be substituted for each other. When closed for the pocket, one leg of each bow slides into the upper legs, and the other is turned inward towards the head.

As a concluding remark, we recommend the draughtsman to choose compasses in which the joint is formed by a box-screw, that can be tightened or relaxed at pleasure. The cheaper kinds have merely a common screw, and these are usually too stiff when first purchased, and inconveniently loose after being some time in wear. A slight turn of the box-screw, by means of the key, keeps the compasses in good working order, neither so stiff as to *spring*, nor so loose as to render them uncertain and unsteady in use.

Plain and Double Scales.

Simply-divided Scales.—Scales are measures and subdivisions of measures laid down with such accuracy, that any drawing constructed by them, shall be in exact proportion in all its details. The plain scale is a series of measures laid down on the face of *one* small flat ruler, and is thus distinguished from the sector, or double scales, in which two similarly-divided rulers move on a joint, and open to a greater or less angle. In the construction of scales, the subdivision must be carried to as low a denomination as is likely to be required. Thus, for a drawing of limited extent, the primary divisions may be feet, and the subdivisions inches; but for one of large area, and without small details, the primaries may be 10 feet, and the sub-

Figs. 219 and 220.

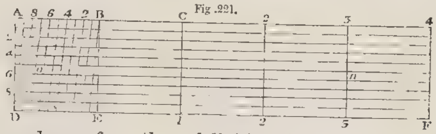


divisions tenths, or one foot each (Figs. 219 and 220). In the case of large surveys, the primaries become miles, and the lesser divisions furlongs. Indeed the natural size or extent of the object or area, and the surface to be occupied by the delineation, must determine the graduation of the scale. But passing from these general remarks, we proceed to the plain scales contained in the drawing case, and laid down on the two sides of a flat ivory ruler, six inches in length.

On one side of the plain scale there is usually a series of simple scales, in which the inch is variously divided, and the primaries subdivided into tenths and twelfths. These may be applied to measurements as inches and tenths, or twelfths; or as feet and tenths, or inches, according to the nature of the drawing. It may be remarked, however, that these small lines of measures are of only limited use, and that the draughtsman must usually lay down a scale with special reference to the work before him; and in all cases it is desirable to have the scale of construction on the margin of the drawing itself, since the paper contracts or expands with every atmospheric change, and the measurements will therefore not agree at all times with a detached scale; and, moreover, a drawing laid down from such detached scale, of wood or ivory, will not be uniform throughout, for on a damp day the measurements will be too short, and on a dry day too long. Mr. Holtzapffel has sought to remedy this inconvenience by the introduction of *paper* scales; but all kinds of paper do not contract and expand equally, and the error is therefore only partially corrected by his ingenious substitution of one material for another.

Diagonal Scale.—The lines to which we have referred give only two denominations, primaries and tenths, or twelfths; but more minute subdivision is frequently required, and this is attained by the diagonal scale, which consists of a number of primary divisions, one of which is divided into tenths, and subdivided into hundredths by diagonal lines (Fig. 221). This scale is constructed in the following manner:—Eleven parallel lines are ruled, inclosing ten equal spaces: the length is set off into ten equal primary divisions, as A B, B C, C 2, &c.; and diagonals are

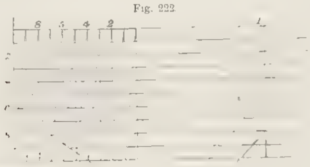
Fig. 221.



then drawn from the subdivisions between A and B, to those between D and E, as shown in the diagram. Hence it is evident that at every parallel we get an additional tenth of the subdivisions, or a hundredth of the primaries, and can therefore obtain a measurement with great exactness to three places of figures. To take a measurement of 168, we place one foot of the dividers on the primary 1

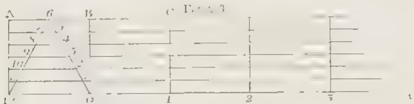
(Fig. 222), and carry it down to the eighth parallel, and then extend the other foot to the intersection of the diagonal, which falls from the subdivision 6, with the parallel that measures the eight-hundredth part. More examples or further explanation would only be tedious. The primaries may of course be considered as yards, feet, or inches; and the subdivisions as tenths and hundredths of these respective denominations. The diagonal scale is very useful and satisfactory if accurately constructed; but there can be no

Fig. 222



question, that one with a Vernier applied to the first subdivisions, would give minute measures with much greater certainty; and no case of instruments ought now to leave the maker without having this addition on one face of the plain scale.

The diagonals may be safely applied to a scale where only one subdivision is required. Thus, if seven lines be ruled, inclosing six equal spaces, and the length be divided into primaries, as A D, B C, &c., the first primary A B may be subdivided into twelfths, by two diagonals running from 6, the middle of A B, to 12 and 0. We have here a

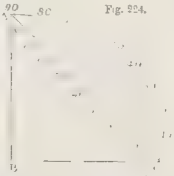


very convenient scale of feet and inches. From C to 6, is 1 foot 6 inches; and from C, on the several parallels, to the various intersections of the diagonals, we obtain 1 foot and any number of inches from 1 to 12. All of which is evident from the figure.

On the face of the plain scale that carries the diagonal one, there is usually a line of inches and tenths, and underneath it a decimal scale. These can be used separately, and in conjunction; and in the latter case the primaries of the decimal scale being taken as feet, the subdivisions of the upper line are inches.

Line of Chords.—This is usually introduced on the plain scale. It is an unequally divided scale, giving the length of the chord of an arc, from 1 degree to 90 degrees. The quadrant, or quarter of a circle, A C, contained between the two radii at right angles, B A and B C, has its extremities joined by the line A C, to which the measures of the chords are to be transferred. The quadrant is divided accurately into nine equal parts; then from C as a centre, each division is transferred by an arc to the line A C, and the chords of every 10 degrees obtained. These primary divisions can be subdivided into tenths, of 1 degree each, by division of the corresponding arcs. This

Fig. 224.



is rather an illustration of the construction, than a true method of performing it. A line of chords can be laid down accurately only from the tabular sines, delicately set off by the beam compasses. In using this scale, it is to be remembered that the chord of 60 degrees is equal to radius. Therefore, to lay down an angle of any number of degrees, draw an indefinite straight line; take in the compasses the chord of 60 degrees, and from one termination of the line, as a centre, describe an arc of sufficient extent; then take from the scale the chord of the required angle, and set it off on the arc; lastly, draw another line from the centre cutting the arc in the measure of the chord. To ascertain the degrees of an angle, extend the angular lines if necessary, that they may be at least equal to the chord of 60 degrees; with this chord in the compasses describe an arc from the angular point; then take the extent of the arc and apply it to the scale, which will show the number of degrees contained in the angle.

The Plain Protractor.—The plain scale is sometimes made of greater width, in order to contain all the preceding lines, and also a protractor for setting off and measuring angles. The most eligible form for this instrument is the circle or half circle, which construction will presently come before us. It will suffice for the present to say, that the plain scale protractor is a portion of a semicircle, having radii drawn from its centre to every degree of its circumference. If, therefore, the centre on the lower side is made to coincide with a given point, an angle of any number of degrees may be measured or set off around its edges.

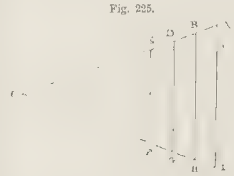
A small roller is sometimes inserted in a slot to make the plain scale serve the purpose of a parallel ruler, but considerable care is necessary in thus applying it, lest the roller slide or shift at either extremity.

Double Scales.

Each of the scales we have described has a fixed measure that cannot be varied; but we come now to speak of those double scales in which we can assume a measure at convenience, and subdivide lines of *any* length, measure chords and angles to *any* radius, &c.

The Sector.—This instrument consists of two flat rulers, united by a central joint, and opening like a pair of compasses. It carries several plain scales on its faces, but its most important lines are in pairs, running accurately to the central joint, and making various angles according to the opening of the sector. The principle on which the double scales are constructed, is contained in the 4th Prop. of the 6th Book of Euclid, which demonstrates that "the sides about the equal angles of equiangular triangles are proportionals," &c. Now let A C I (Fig. 225) be a sector, or, in other words, an arc of a circle contained between two radii; and let C A, C I, be a pair of sectoral lines, or a double scale. Draw the chord A I, and also the lines B H, D G, E F, parallel to A I.

Fig. 225.



Then shall C E, C D, C B, C A, be proportional to E F, D G, B H, and A I respectively. That is, as C A : A I : : C B : B H, &c. Hence at every opening of the sector, the transverse

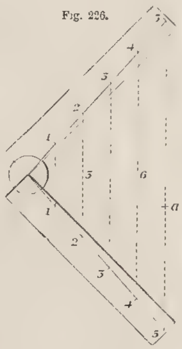
distances from one ruler to another, are proportional to the lateral distances, measured on the lines C A, C I; and thus we may apply *any* radius transversely to the line of chords to measure or lay down any given or required angle; and apply *any* line transversely to the line of lines, to divide it in any required proportions. The sector is therefore seen to be of universal application, whilst the use of plain scales is limited and special.

Plain Scales on the Sector.—On the outer edge of the sector is usually given a decimal scale from 1 to 100; and in connection with it, on one of the sides, a scale of inches and tenths. These are identical with the lines on the plain scale, previously mentioned, but the latter are more commodiously placed for use. On the other side we have logarithmic lines of numbers, sines, and tangents; but as these are more complicated than the ordinary plain scales, we defer the consideration of them until we have discussed the double scales.

Sectoral Double Scales.—These are respectively named the lines of lines, chords, secants, sines, and tangents. These scales have one line on each ruler, and the two lines converge accurately in the central joint of the sector.

The Line of Lines.—This is a line of 10 primaries, each subdivided into tenths, thus making 100 divisions. Its use is to divide a given line into any number of equal parts; to give accurate scale measures for the construction of a drawing; to form any required scale; to divide a given line in any assigned proportion; and to find third, fourth, and middle proportionals to given right lines. The scale can be applied to other purposes; but, if we take up those mentioned, they will be sufficient illustrations of its uses. Before entering upon these propositions, we would remark that a *lateral* distance is one taken from the centre down either half of the scale; and a *transverse* distance is one measured across from scale to scale. Thus (Fig. 226), *a* 1, *a* 2, *a* 3, &c., are lateral distances; and 1.1, 2.2, 3.3, &c., transverse distances.

Fig. 226.



1. To divide a given line into 8 equal parts. Take the line in the compasses, and open the sector so as to apply it transversely to 8 and 8, then the transverse from 1 to 1 will be the eighth part of the line. If the line is to be divided into 5 equal parts, apply it transversely by the compasses to 10 and 10, and the transverse of 2 and 2 is the fifth part. When the line is too long to fall within the opening of the sector, take the half or the third of it. Thus, if a line of too great length is to be divided into 10 parts, take the half and divide into 5 parts; or if into 9 parts, take the third and divide into 3 parts. And in other cases it may be necessary to divide the portion of the line into the original number of parts, and set off twice or thrice to obtain the required division of the whole.

2. To use the line of lines as a scale of equal measures. Open the sector to a right angle, or nearly so, and obtain dimensions by transverse measures from scale to scale, taking care that the points of the compasses are directed to the same division on both rulers. Thus, the transverse measures to the primaries 1.1, 2.2, &c., will give any denomination, as feet or inches, and similar measures to the *same* subdivisions on both sides will give tenths.

3. To form any required scale—say, one in which 285 yards shall be expressed by 18 inches. Now, as 18 inches cannot be made a transverse, take in the compasses 6 inches, the third part, and make it a transverse to the lateral distance 95, which is the third of 285. The required scale is then made; the transverse measures to the primaries being 10 yards, and to the subdivisions so many additional yards.

4. To divide a given line in any assigned proportion—say, a line of 5 inches in the proportion of 2 to 6. Take 5 inches in the compasses, and apply it to the transverse of 8.8, the sum of the proportions; then will the transverse distances 2.2, 6.6, divide the given line as required.

5. To find a third proportional to the numbers 9 and 3, or to lines 9 inches and 3 inches in length. Make 3 inches a transverse distance to 9.9; then take the transverse of 3.3, and this measured laterally on the scale of inches will give 1 inch. For 9 : 3 : : 3 : 1.

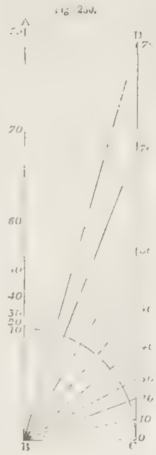
6. To find a fourth proportional to the numbers 10, 7, 3, or to lines measuring 10, 7, and 3 inches respectively. Make 7 inches a transverse from 10 to 10, then the transverse 3.3 will measure on the scale of inches $2\frac{1}{10}$. For 10 : 7 : : 3 : $2\frac{1}{10}$.

7. To find a middle proportional between the numbers 4 and 9, or between 2 lines measuring 4 and 9 inches respectively. To perform this operation the line of lines on the one leg of the sector must first be set exactly at right angles to the one on the other leg. This is done by taking 5 of the primary divisions in the compasses, and making this extent a transverse from 4 on one side to 3 on the other. For 3, 4, and 5, or any of their multiples, form a right-angled triangle. The sector being thus adjusted, take in the compasses a lateral distance of 6 primaries and 5 tenths, half the sum of the two lines or numbers, and apply this measure transversely from 2 primaries and 5 tenths, half the difference, when the other point of the compasses will reach the primary 6 on the opposite leg of the sector. For 4 : 6 : : 6 : 9.

The line of lines is marked L on each leg of the sector; and it is to be observed that all measures are to be taken from the inner lines, since these only run accurately to the centre. This remark will apply to all the double sectoral lines. With reference to some of the preceding operations by the line of lines, we may admit that they are suggestive rather than practically useful. They familiarize the young draughtsman with the capabilities of scales, and offer him useful hints for the general construction and management of lineal measures.

The Line of Chords.—The scale of chords on the sector has the same advantage over that on the plain scale that the line of lines has over the simply-divided single scales. With the line of lines we operate on any given line that will come within the opening of the sector; and with the line of chords we can work with any radius of similar extent. This last is constructed by making the lateral distance of the chord of 60 degrees, which is radius, equal in length to the line of lines. All the intermediate degrees between 1 and 60, are then set off laterally from the centre, on both rulers, by taking on the line of lines a measure equal to twice the natural sine of half the angle. Thus, for

right angles to B C. A B is a line of secants, formed by transfer with the compasses of the radial lines from the centre B. It is therefore seen that the radius, tangent, and secant, are the base, perpendicular, and hypothenuse of a right-angled triangle. A line of sines would be formed by graduating the radius 10 B, with lines drawn through the degrees of the quadrant, and parallel to B C.



The lines of sines and tangents are frequently of use to the draughtsman in the determination of a number of points through which an eccentric curve can be drawn. We here give two examples of the use of the sectoral lines in the solution of questions in Trigonometry.

1. A right-angled triangle has base 12, perpendicular 16; required the hypothenuse.—Set the sector at right angles, by making the lateral distance of 5 on the line of lines a transverse to 3 and 4. Then take the transverse of 12 on one leg to 16 on the other, and this, measured on the line of lines, will give 20 for the hypothenuse.

2. A right-angled triangle has perpendicular 30, and the angle opposite thereto 37 degrees; required the hypothenuse.—Take 30 from the line of lines, and make it a transverse to 37 degrees on the line of sines, then the transverse of 90.90, will measure 50 on the line of lines, the length of the hypothenuse.

Logarithmic Lines.

The Line of Numbers.—This line, commonly called Gunter's Line, and marked N on the sector, is divided into spaces forming a geometrical series, and is simply a table of logarithms expressed by relative measures of length. It is constructed in the following manner:—The entire line is divided into two equal parts, and each of these parts into nine unequal primary divisions, corresponding to the logarithms they are to represent. These primaries are to be the measures of the numbers 2 to 9, whose logarithms may be considered 30, 47, 60, 70, 78, 84, 90, and 95, as will be seen on reference to the ordinary tables. To make a scale of equal parts for setting off these quantities, take one-half of the line in the compasses and make it a transverse to 10.10 on the line of lines. Then take successively the transverse distances of 30.30, 47.47, &c., and set them off from the commencement on the first half of the line of numbers for the primary divisions 2, 3, &c. These same spaces may next be transferred to the second half of the line for *its* primary divisions. Thus we have obtained the logarithms of 20, 30, 40, 50, 60, 70, 80, 90, 100 on the first half; and those of 100, 200, &c., on the second half. Now, for the subdivision of the space between 1 and 2, we must set off from the commencement of the line, in succession, the logarithms of 11, 12, &c., to 19; and for that between 2 and 3, the logs. of 21, 22, &c., to 29; and thus proceed till we come to the space between 6 and 7, which is too short to admit the decimal divisions. Graduate therefore this last space, and all onward to 10, into two-tenths; and consequently take the logs. of 62, 64, 66, 68; 72, 74, 76, 78; &c. All these subdivisions, set off from the commencement on the first half of the line, may also be set off from 1 in the middle, in the second half. Thus, we have found on the one half, the logs. of tens and units, and on the second half those of hundreds and tens. But there is a farther subdivision of the space between 1 and 2 on the second half, which is graduated to twenty places; and this halving of the first subdivisions is effected by setting off successively from 1, the logs. of 105, 115, 125, &c. This done, the line is constructed.

In using this line any value may be attached to the primary divisions, merely observing their relative proportion to each other. Thus, if the primaries on the first half are units, and their subdivisions tenths, those on the second half will be tens and their subdivisions units. Whatever is the value of a primary or subdivision on the first half, the corresponding primary and subdivision on the second half will have ten times that value. We illustrate the use of the line by a few examples. Take off the measures of the numbers 896, 1150, 2050. For the first, place one foot of the compasses at the beginning of the line on the left hand, and extend the other over eight primaries and four subdivisions, and nearly to the end of the fifth subdivision. For the second, extend over the ten primaries of the first half and three subdivisions of the second half. For the third, extend over the first ten primaries, and one primary of the second half, and half a subdivision beyond. To multiply, say 135 by 48: take the extent from 1 on the left hand to 48 in the first interval, and apply it to 135 in the second interval, when it will reach to 648, or 6480. To divide 6480 by 135: extend backwards from 135 to 1 on the left hand, and this will measure back from 6480 to 48. To find a fourth proportional to the numbers 3, 8, and 15: take the extent from 3 to 8 in the first interval, and this will reach from 15 to 40 in the second interval; for 3 : 8 :: 15 : 40.

The Line of Sines.—This line gives the sines of angles to 90 degrees in a geometric series; their logarithms being expressed by relative spaces. It is constructed by laying down the logarithms of the sines from the same scale of equal parts by which the line of numbers was measured. Its two intervals are not, however, of equal length; and hence we cannot set off the primaries in both from the same measure. We therefore require a scale of equal parts of twice the length, or one the whole length of the line of numbers, to enable us to set off all the sines from the commencement of the scale on the left hand. The simplest way is to make the length of the line of numbers, a transverse to 10.10 on the sectoral line of lines, and take the transverse measures of *half* the logarithms. Now the logs. of the primaries, 1, 2, 3, &c., to 10, in the first interval, and of 20, 30, &c., to 90, in the second interval, are these: 242, 543, 719, 843, 940, 1019, 1085, 1143, 1194, 1239; 1534, 1699, 1808, 1884, 1937, 1972, 1993, 2000. Take, therefore, the halves of these logs. tranversely from the line of lines, and lay them down successively on the line of sines, from the beginning of the scale. The subdivision of the primaries into minutes and degrees is proceeded with in the same manner. The degrees in the first interval are divided into six spaces, each being 10 minutes; but between 10 and 20, in the second interval, there are 20 subdivisions, each represent-

ing 30 minutes, or half a degree: between 20 and 30, and 30 and 40, there are 10 subdivisions, each being 1 degree: between 40 and 50, 50 and 60, 60 and 70, there are 5 graduations, each 2 degrees; and the space between 70 and 90 admits only of one subdivision to divide it for 80 and 90 degrees. The commencement of the scale is interfered with by the sectoral line of sines, so that the measure of 50 minutes is the least sine that can be laid down on the logarithmic line. With this sine, whose log. is 162, we commence the subdivisions, and then proceed to the sines of 1° 10′, 1° 20′, &c.; 2° 10′, 2° 20′, &c., until the graduation is completed.

There is another method of construction, by which the sines are measured off from the termination of the line on the right hand. For this purpose the logs. of the arithmetical complements of the sines are taken, that is to say, the difference between them and radius. Thus, the log. of the sine of 30 degrees, taking all the places of figures, is 9·6989700, and this deducted from radius, or 10·0000000, leaves a remainder of ·3010300. If, therefore, 301, or its half by the proposed scale, be laid from the end of the line of sines at the right hand, it will reach the graduation of 30 degrees. There is yet another method: in place of the arithmetical complement of the sine, take the secant of the complementary angle, viz., 60 degrees, and set off from the right hand as in the former case. We mention these various modes of construction to call the young draughtsman's attention to the relation between different angles, and as suggestions for more scientific inquiry concerning them.

The manner of taking off a logarithmic sine from the scale is obvious: one foot of the compasses is placed at the commencement, and the other extended to the required degree or minutes. The use of the line in conjunction with the line of numbers may be illustrated by one example. The base of a right-angled triangle is 30, and the angle opposite to it 30 degrees; what is the hypothenuse?

Now, Sine of Angle : 30 : : Radius : Hypothenuse.

Set one foot of the compasses on 30 degrees, and extend the other to 30 on the line of numbers; and with this opening, set one foot on 90 degrees of the line of sines, and the other foot will reach to 60 on the line of numbers—the hypothenuse required.

The Line of Tangents.—This line gives the logarithmic measures of the tangents to 45 degrees, and thence backwards to 88° 30′. The tangent of 45 degrees being equal to radius, or the line of numbers, the graduation cannot be extended beyond this angle; but the upper tangents are obtained by reckoning backwards, 40 for 50, 30 for 60, 20 for 70, &c.; and this method of obtaining the longer tangents is compensated by a peculiarity of operation when the line is wrought in conjunction with the line of numbers. This scale is constructed by measuring off, successively, from the commencement at the left hand, the logarithms of the primaries and subdivisions as required. Thus, the first interval has for its primaries the degrees from 1 to 10; and, in the second, every primary is 10 degrees, except the last, which is only 5. The subdivisions in the first interval are ten minutes; and in the second, between 10 and 20 and 20 and 30, they are 30 minutes, or half a degree: and from 30 to 45, 1 degree each. Make a scale of equal parts, as for the sines, by applying the length of the line of numbers to 10·10 on the line of lines; then take the transverses of half the logarithmic tangents found in the tables. Thus the logs. of 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 20, 30, 40, 45 degrees, are 242, 543, 719, 844, 941, 1021, 1089, 1148, 1199, 1246; 1561, 1761, 1924, 2000. Take therefore the halves of these numbers from the scale, and transfer them to the line for the primaries. The subdivisions are commenced at 1° 30′, whose log. is 418; and then continued 1° 40′, 1° 50′, 2° 10′, &c., until completed. As in the case of the sines, the line of tangents may likewise be constructed by laying down the arithmetical complements of the tangents backwards, from 45 degrees to the commencement of the scale.

The length of a logarithmic tangent is measured off from the commencement of the line at the left hand, by extending the compasses to the degree or minute required. We give two examples of the application of the scale to the solution of questions in trigonometry. 1. The base of a right-angled triangle is 25, and the perpendicular 15; what is the angle opposite to the perpendicular? Here, if the base is considered radius, the perpendicular will be the tangent of the angle opposite to it; therefore,

As 25 : 15 : : Radius : Tangent.

Extend the compasses from 15 to 25 on the line of numbers, and this opening will reach backwards from 45 degrees on the line of tangents to 31 degrees, the angle required. 2. The base of a right-angled triangle is 20, and the angle opposite to the perpendicular 50 degrees; what is the perpendicular?

As Radius : Tan. 50° : : 20 : Perpendicular sought.

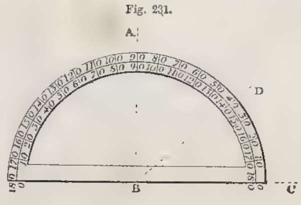
Extend the compasses from 45 degrees to 50 on the line of tangents, and apply them, thus opened, from 20 towards the right hand, to 23¾, the perpendicular. This example shows the method of working when the angle exceeds 45 degrees. The extent taken from the tangents is only from 45 to 40, the complement of 50 degrees; and we therefore apply it from 20 towards *the right hand* to obtain the length of the perpendicular; but had the angle been 40 degrees, the extent would have been applied from 20 towards *the left hand*, to 16¾, which would, in that case, have been the perpendicular.

We have now gone systematically through the sector, which contains a great deal of what may be termed mechanical mathematics, and offers much that is valuable to the draughtsman in the way of suggestion for the construction and management of scales.

Protractors.

We have already referred to the protractor on the plain scale. The semicircle (Fig. 231), though different in form, is the same in principle. It is a half circle of brass, or other metal, having a double graduation on its circular edge. The degrees run both ways to 180; so that any angle, from 1 to 90 degrees, may be set off on either side. Each graduation marks an angle and its supplement; thus, 10, 20, 30, coincide with 170, 160, 150; and are the

Fig. 231.

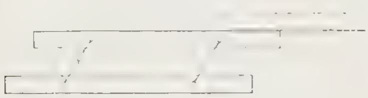


supplements of each other. An angle is protracted or measured by this instrument with great facility. To protract an angle, draw a line, and lay the straight edge of the protractor upon it, with its centre on the point where the angle is to be formed: the required number of degrees is next marked off close to the circular edge: the instrument is then laid aside, and a line drawn from the angular point, to the one which measures the extent of the angle. Thus in the figure, B is the centre, or angular point, D the measure of the angle, and B D the line by which it is formed. The converse operation of measuring an angle is equally simple: the angular point and the centre of the protractor are made to coincide, and the straight edge of the instrument is laid exactly upon one line of the angle, when the other will intersect the circular edge, and indicate the number of degrees. The plain scale protractor is used in the same manner; but it is by no means so convenient an instrument as the semicircle. Either of them may be employed occasionally to raise short perpendiculars. For this purpose, make the centre and the graduation of 90 degrees coincide with the line upon which the perpendicular is to be raised.

Parallel Ruler.

This is a well-known instrument, consisting of two rulers connected by slides, moving on pivots, and so adjusted, that at every opening of the instrument, the rulers and the slides form a parallelogram. In use, its edge is made to coincide exactly with the line to which others are to be drawn parallel: the lower ruler is then held firmly down, and the upper one raised to any required distance, when a line drawn along its edge will be parallel to that

Fig. 232.



from which it started (Fig. 232). There are several methods of uniting the rulers; but we are not aware that any one has very decided advantages over the others. The ordinary form, as shown in the figure, is perhaps the simplest, and, therefore, the best. The right angled straight-edges of the drawing-board and the T-square, are the surest means of all for drawing parallels and perpendiculars; and the parallel ruler will never be used when these can be employed.

Fig. 233.

Drawing Pens.

The drawing pen differs from the pen-leg of the compasses only in its having a long straight handle, the top of which is sometimes made to unscrew and form a tracer or pin, to set off angles by the edge of the protractor (Fig. 233). The dotting pen is a similar modification of the dotting leg of the moveable compasses. The use of both instruments is to draw straight, continuous, or dotted lines in ink. A place is usually provided in the drawing case for a thin pencil, to rule in straight lines, that may afterwards either be obliterated or made permanent by the ink pen.

Pricker.

This is a simple instrument, consisting of a fine needle-point firmly fixed into the end of a wooden or ivory holder, for pricking off distances, the positions of lines, &c., upon the paper. It is so used in conjunction with portable scales, the edges of which, being graduated, are applied to the sheet, and measure off the required distance. The pricker to this extent supersedes the dividers, and may be so employed with facility and accuracy. It is also used in copying drawings, by placing the drawing on the top of the sheet upon which the copy is to be made, and pricking through upon the vacant sheet the positions of the lines, angles, and centres of the drawing; thus the copying process is expedited. The ladies' crochet needle-holder makes a neat handle for the pricking needle.

Drawing Paper.

Drawing paper, properly so called, is made to certain standard sizes, as follow:—

Demy, ...	20	inches by	15¼	inches.
Medium,	22¼	,,	17½	,,
Royal, ...	24	,,	19¼	,,
Super-Royal,	27¼	,,	19¼	,,
Imperial, ...	30	,,	22	,,
Elephant, .	28	,,	23	,,
Columbier, ...	35	,,	23½	,,
Atlas, ...	34	,,	26	,,
Double Elephant, ...	40	,,	27	,,
Antiquarian,	53	,,	31	,,
Emperor, ...	68	,,	48	,,

Of these, Double Elephant is the most generally useful size of sheet. Demy and Imperial are the other useful sizes. Whatman's white paper is the quality most usually employed for finished drawings: it will bear wetting and stretching without injury, and, when so treated, receives shading and colouring easily and freely. For ordinary sketching or working drawings, where damp-stretching is dispensed with, cartridge paper, of a coarser, harder, and tougher quality, is to be preferred. It bears the use of india-rubber well, receives ink on the original undamped surface freely, shows a good line, and, as it does not absorb very rapidly, tinting lies evenly upon it. For delicate small-scale line-drawing, the thick blue paper, such as is made by Harris for ledgers, &c., imperial size, answers exceedingly well; but it does not bear damp stretching without injury, and should be merely pinned or waxed down to the board. With good management, there is no ground to fear the shifting of the paper. Good letter-paper receives light drawing very well: of course it does not bear much fatigue.

Large sheets, destined for rough usage and frequent reference, should be mounted on linen, previously damped, with a free application of paste.

Tracing paper is a preparation of tissue paper, rendered transparent and qualified to receive ink lines and tinting without spreading. When placed over a drawing already executed, the drawing is distinctly visible through the paper, and may be copied or *traced* directly by the ink-instruments: thus an accurate copy may be made with great expedition. Tracings may be folded and stowed away very conveniently; but, for good service, they should be mounted on cloth, or on paper and cloth, with paste.

Tracing paper may be prepared from double-double

crown tissue paper by lightly and evenly sponging over one surface with a mixture of one part of raw linseed oil or nut-oil, and five parts of turpentine. Five gills of turpentine, and one of oil, will go over from $1\frac{1}{2}$ to 2 quires of twenty-four sheets.

Tracing cloth is a similar preparation of linen, and has the advantage of toughness and durability.

Drawing Boards.

Drawing boards are made truly rectangular, and for common use may be of two sizes—41 by 30 inches, to carry double-elephant paper, with a margin; and 31 by 24 inches, for imperial and all smaller sizes. Boards much smaller than this are unsuited for ordinary work, but may be necessary for particular purposes. Drawing boards may be of mahogany, oak, or yellow pine, well seasoned; $\frac{1}{2}$ inch or $\frac{9}{16}$ inch thick for mahogany, and 1 inch for pine, or say $1\frac{1}{8}$ inch to allow for dressing up. They should be barred and dowelled at the ends, to stiffen them, and enable them to resist any tendency to twist, as well as to afford a suitable edge for the working of the drawing square. It would be an improvement to line the working end of the pine board with a strip of mahogany or other hard wood, as it is liable to wear slightly round at the corners.

Boards are occasionally made as loose panels placed in a frame, all flush on the drawing surface, and bound together by bars on the other side.

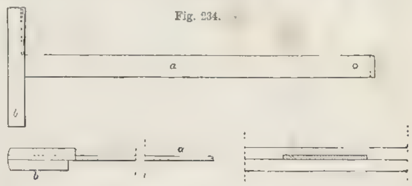
Drawing paper may be fixed down upon the ordinary board, either by damping, and gluing its edges, or by simply fixing it at the corners, and at intermediate points, if necessary, with pins or with sealing wax or wafers. The latter fixing is sufficient where no shading or colouring is to be applied, and if the sheet is not too long a time upon the board. It has the advantage, too, of preserving to the paper its natural quality of surface. With mounted paper, indeed, there is no other proper way of fixing. For large, coloured, or elaborate drawings, however, a damp-stretched sheet is preferable: with colouring or flat tinting, indeed, damp-stretching is indispensable, as the partial wetting of loose paper by water-colour causes the surface to buckle. Damp-stretching is done in the following way: lay the sheet flat on the board, with that side undermost which is to be drawn upon, and pare the thick edges from the paper; draw a wet sponge freely and rapidly over the upper side beginning at the centre, damping the entire surface, and allow the sheet to rest for a few minutes, till it be damped through, and the surface-water disappears. Those parts which appear to revive sooner than others, should be retouched with the sponge. The damping should be done as lightly as possible, as the sponge always deprives the paper of more or less of its sizing. The sheet is now turned over and placed fair with the edges of the board—sufficiently clear of the working edges to permit the free action of the drawing square. The square, or an ordinary straight-edge is next applied to the paper, and set a little within one edge, say about $\frac{3}{16}$ of an inch, which is then turned up over the square, and smeared all along with melted glue. The paper is then folded back and pressed down by the square, after which the end of a paper-folder, or other smooth article, is rubbed along the "lap," with a piece of stiff paper interposed, to press out the superfluous glue and bring the paper into intimate contact with the board. The same operation being rapidly applied in succession to the other edges, the sheet is left to dry, and ultimately, by the contraction, turns out perfectly flat and tense. When melted glue is not to be had conveniently, a cake of glue may be dipped in water and rubbed on the margins of the board at the proper places. Lip glue, or artists' glue, which dissolves very readily, may be used in this case.

With loose panelled boards, as described, the panel is taken out, and the frame inverted; the paper being first damped on the back with a sponge, slightly charged with water, is applied equally over the opening to leave equal margins, and is pressed and secured into its seat by the panel and bars. This is a ready enough way of laying a sheet, and for damp sheets is more expeditious than the gluing system. But the large margin required diminishes the size of the sheet, and for general use plain boards are sufficient.

T-Square.

The T-square (Fig. 234) is a blade or "straight-edge" *a*, usually of mahogany, fitted at one end with a stock *b*,

Fig. 234.



Details of T-Square.

applied transversely at right angles. The stock being so formed as to fit and slide against one edge of the board, the blade reaches over the surface, and presents an edge of its own at right angles to that of the board, by which parallel straight lines may be drawn upon the paper. To suit a 41-inch board, the blade should measure 40 inches long clear of the stock, or one inch shorter than the board, to remove risk of injury by overhanging at the end: it should be $2\frac{1}{2}$ inches broad by $\frac{3}{32}$ inch thick, as this section makes it sufficiently stiff laterally and vertically. If thinner, the blade is too slight and too easily damaged by falls and other accidents, and is liable to warp; if thicker, it is too heavy and cumbersome; if broader, it is heavier without being stiffer. The tip of the blade may be secured from splitting by binding it with a thin strip inserted in a saw-cut as shown. The stock should be 14 inches long, to give sufficient bearing on the edge of the board, 2 inches broad, and $\frac{5}{8}$ inch thick, in two equal thicknesses glued together. With a blade and stock of these sizes, a well proportioned T-square may be made, and the stock will be heavy enough to act as a balance to the blade, and to relieve the operation of handling the square. The blade should be sunk flush into the upper half of the stock on the inside, and very exactly fitted. It should be inserted full breadth, as shown in the figure; notching and dovetailing is a mistake, as it weakens the blade and adds nothing to the security. The lower half of the stock should be only $1\frac{3}{4}$ inches broad, to leave a $\frac{1}{4}$-inch check or lap, by which the upper half rests firmly on the board, and secures the blade lying flatly on the paper.

For the second size of board, 31 inches long, the blade should be not more than $30\frac{1}{2}$ inches, of the same scan-

tling as above, or rather thinner; and the stock a little shorter.

One-half of the stock *c* (Fig. 235), is in some cases made loose, to turn upon a brass pin to any angle with the blade *a*, and to be clenched by a screwed nut and washer. The turning stock is useful for drawing parallel lines obliquely to the edges of the board. In most cases, however, the sector, and the other appendages to be afterwards described, answer the purpose, and do so more conveniently. A square of this sort should be rather as an addition to the fixed square, and used only when the bevil edge is required, as it is not so handy as the other.

Fig. 235.

Drawing Square, with Swivelling Stock.

The edges of the blade should be very slightly rounded, as the pen will thereby work the more freely. It is a mistake to chamfer the edges—that is, to plane them down to a very thin edge, as is sometimes done, with the object of insuring the correct position of the lines; for the edge is easily damaged, and the pen is liable to catch or ride upon the edge, and to leave ink upon it.

A small hole should be made in the blade near the end, by which the square may be hung up out of the way when not in use.

No varnish of any description should be applied to the T-square, or indeed to any of the wood instruments employed in drawing. The best and brightest varnish will soil the paper long after it has been applied and furbished up. The natural surface of the wood cleaned and polished occasionally with a dry cloth, is the best and cleanest for working with.

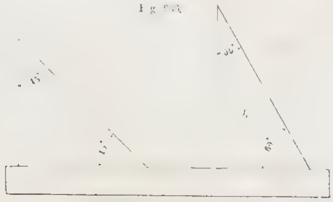
Straight-edges and Triangles.

These appendages to the T-square greatly facilitate the operations of the draughtsman. They should be of close-grained hardwood, as mahogany, well-seasoned; straight-edges, when 5 feet long and upwards, may be of ribbon-steel. Wood is more easily kept clean, and is less likely to soil the paper.

Straight-edges should, like square blades, be just broad and thick enough for the necessary stiffness, and bevelled a little at one edge. The smallest (as in Fig. 236) may be 9 or 10 inches long, $\frac{7}{8}$ inch broad, and $\frac{1}{4}$ inch thick.

Triangles, or *set-squares*, as they are sometimes called, should be barely $\frac{3}{32}$ inch thick, and flat on the edges, to wear well. They should be right angled, one of them *a* (Fig. 236), being made with equal sides, and angles of 45

Fig. 236.



Straight-edge and Set-squares.

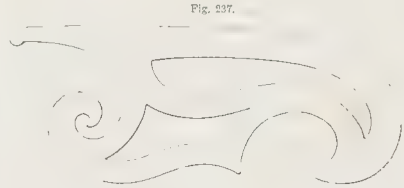
degrees each; the other *b*, with angles of 60 and 30 degrees. The former, by means of its slant side, is very useful in laying off square figures: the vertical side, too, saves a deal of shifting of the T-square, as, when the horizontal edge is applied to that of the square, short perpendicular lines may be drawn by the upright edge. The most convenient size for general use measures from $3\frac{1}{2}$ to 4 inches on the side. A larger size, 8 or 9 inches long on the side, is convenient for use in making large scale drawings. Applying one or other edge of the triangle *b*, to the square, the slant side gives at once the boundaries of all hexagonal and triangular figures. This triangle may be of two sizes, 5 inches high and upwards. Of the two set-squares, the second is the more convenient for general use in drawing perpendiculars, as it is larger and has a shorter base, and is more easily handled. Still sharper set-squares are sometimes used; also compound triangles, having the slant-edge broken into two lines of different slopes. The latter is not to be recommended. Circular openings are sometimes made in the body of the triangle for facility in handling. They are of no great use in that respect, but they allow of the triangles being hung up.

Triangles are further useful in connection with each other, or with the straight-edge, for drawing short parallels and perpendiculars without the use of the T-square, as shall be exemplified in the proper place.

Sweeps and Variable Curves.

For drawing circular arcs of large radius, beyond the range of the ordinary compasses, thin slips of wood, termed

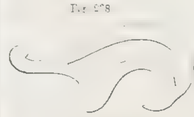
Fig. 237.



Variable Curve, one fourth full size.

sweeps, are usefully employed, of which one or both edges are cut to the required circle. For curves which are not circular, but variously elliptic or otherwise, "universal sweeps," made of thin wood, of variable curvature, are very serviceable. The two examples (Figs. 237, 238) have been found from experience to meet almost all the requirements of ordinary drawing practice. Whatever be the nature of the curve, some portion of the universal sweep will be found to coincide with its commencement, and it can be continued throughout its extent by applying successively such parts of the sweep as are suitable, taking care, however, that the continuity is not injured by unskilful junction.

Fig. 238.



Variable Curve, One fourth full size.

Pencils.

Pencils are of various qualities, distinguished by letter-marks. The H B (hard and black) quality is usually recommended; but it is too soft to retain long the firm point required for the correct execution of mechanical drawings; and, besides, the softer pencils are the more unctuous, and therefore the less ready in taking on

ink lines than the harder. F pencils work pretty well upon smooth paper; but for drawing paper of a thick and rougher quality, especially after having been damp-stretched, H H, and still better, H H H pencils (of two or three degrees of hardness), are better suited to retain their sharpness. They are further recommended by the lightness and delicacy of the lines that may be thrown off by them; for when a pencil drawing is made with the view of being done over with ink lines, the excellence of these lines, as well as the readiness with which they are produced, depends much upon the quality of the pencilling.

Pencil lines, intended to be made permanent in ink, ought to be entered very delicately, and made just so dark as to render them distinct, for the more lightly they are executed, the fitter they are to receive the ink. A little practice, and a steady hand, will secure the end proposed. The pencil need not be held tightly; a slight hold, without slackness, is what is wanted, inclined a little to the side toward which the line is drawn. Besides a drawing pencil for straight lines, it is well to have one a little softer for sketching in small circles, not requiring the regular application of the pencil bows, as the rounding and filling up of corners, ends of bolts, and the like. Many good draughtsmen consider the following mode of cutting as the one best calculated to prepare the pencil for straight line drawing:—In the first place, it should be cut down to the flat side of the lead, in a plane nearly parallel to the axis; then cut away on the opposite side to a bevel considerably inclined, and cut, likewise, transversely, at equal angles. The lead being thus laid bare, should be pared down gradually on the three inclined sides, till brought to a fine edge viewed laterally, and a flat round point in the other aspect (as in Fig. 239). The less inclined side, when applied to a square, admits of the point being brought close to the edge, by which the line is more certainly drawn; and the roundness of the point keeps the pencil longer in working order. The sharpening of a sketching pencil is simply conical, and brings it to a fine point, and many prefer the lining pencil cut also in this manner. To produce a good working pencil, a sharp knife is indispensable; if the knife be blunt, the point will invariably break away before it is properly brought up—a very fine flat file, or a pumice-stone, or two files set in a stock, so that the section of the blades shall be like the letter V, are sometimes used to bring up the point of the pencil. Amongst the minor things requiring special attention, the cutting and pointing of pencils is one of some consequence both in point of economy and pleasant working. A carelessly cut pencil is constantly requiring a knife; and, at the same time, it works with much uncertainty along the straight edge of the square.

Fig. 239.

Drawing Pencil.

Pins.

Pins for holding down sheets not fixed by glue or otherwise, are indispensable. These should be made with a broad flat head, of brass, and rounded so as to permit the squares to slide easily over it, and the stem, of steel, rivetted into the head. Fig. 240 shows a good form of pin. The stem is in some cases screwed in, but is then liable to wear loose: the taper of the stem should be moderate, so as not to work out when fixed into the board.

Fig. 240.

General Remarks on Drawing.—Management of the Instruments.

In constructing preparatory pencil-drawings, it is advisable, as a rule of general application, to make no more lines upon the paper than are necessary to the completion of the drawing in ink; and also to make these lines just so dark as is consistent with the distinctness of the work. And here we may remark the inconvenience of that arbitrary rule, by which it is by some insisted that the pupils should lay down in pencil every line that is to be drawn, before finishing it in ink It is often beneficial to ink in one part of a drawing, before touching other parts at all: it prevents confusion, makes the first part of easy reference, and allows of its being better done, as the surface of the paper inevitably contracts dust, and becomes otherwise soiled in the course of time, and therefore the sooner it is done with the better.

Circles and circular arcs should, in general, be inked in before straight lines, as the latter may be more readily drawn to join the former, than the former the latter. When a number of circles are to be described from one centre, the smaller should be inked first, while the centre is in better condition. When a centre is required to bear some fatigue, it should be protected with a thickness of stout card glued or pasted over it, to receive the compass-leg, or a piece of transparent horn should be used, as before remarked when treating of compasses.

India-rubber is the ordinary medium for cleaning a drawing, and for correcting errors made in pencilling. For slight work it is quite suitable; but its repeated application raises the surface of the paper, and imparts a greasiness to it, which spoil it for fine drawing, especially if ink-shading or colouring is to be applied. It is much better to leave trivial errors alone, if corrections by the pencil may be made alongside without confusion; as it is, in such a case, time enough to clear away superfluous lines when the inking is finished.

For cleaning a drawing, a piece of bread two days old is preferable to india rubber, as it cleans the surface well and does not injure it. When ink lines to any considerable extent have to be erased, a small piece of damped soft sponge may be rubbed over them till they disappear. As, however, this process is apt to discolour the paper, the sponge must be passed through clean water, and applied again to take up the straggling ink. For small erasures of ink lines, a sharp rounded pen-blade applied lightly and rapidly does well, and the surface may be smoothed down by the thumb-nail or a paper-knife handle. In ordinary working drawings a line may readily be taken out by damping it with a hair pencil and quickly applying the india-rubber; and, to smooth the surface so roughened, a

light application of the knife is expedient In drawings intended to be highly finished, particular pains should be taken to avoid the necessity for corrections, as everything of this kind detracts from the appearance.

In using the square, the more convenient way is to draw the lines off the left edge, with the right hand, holding the stock steadily but not very tightly, against the edge of the board with the left hand. The convenience of the left edge for drawing by, is obvious, as we are able to use the arms more freely, and we see exactly what we are doing.

To draw lines in ink with the least amount of trouble to himself, the draughtsman ought to take the greater amount of trouble with his tools. If they be well made, and of good stuff originally, they ought to last through three generations of draughtsmen; their working parts should be carefully preserved from injury; they should be kept well set, and above all, scrupulously clean. The setting of instruments is a matter of some nicety, for which purpose a small oil-stone is convenient. To dress up the tips of the blades of the pen, or of the bows, as they are usually worn unequally by the customary usage, they may be screwed up into contact, in the first place, and passed along the stone, turning upon the point in a directly perpendicular plane, till they acquire an identical profile. Being next unscrewed, and examined to ascertain the parts of unequal thickness round the nib, the blades are laid separately upon their backs on the stone, and rubbed down at the points, till they be brought up to an edge of uniform fineness. It is well to screw them together again, and to pass them over the stone once or twice more, to bring up any fault; to retouch them also on the outer and inner side of each blade, to remove barbs or frasing; and finally to draw them across the palm of the hand.

The china-ink, which is commonly used for line-drawing, ought to be rubbed down in water to a certain degree:—avoiding the sloppy aspect of light lining in drawings; and making the ink just so thick as to run freely from the pen. This medium degree may be judged of after a little practice by the appearance of the ink on the pallet. The best quality of ink has a soft feel, free from grit or sediment when wetted and rubbed against the teeth, and it has a musky smell. The rubbing of china-ink in water tends to crack and break away the surface at the point: this may be prevented by shifting at intervals the position of the stick in the hand while being rubbed, and thus rounding the surface. Nor is it advisable, for the same reason, to bear very hard, as the mixture is otherwise more evenly made, and the enamel of the pallet is less rapidly worn off. When the ink, on being rubbed down, is likely to be for some time required, a considerable quantity of it should be prepared, as the water continually vaporizes: it will thus continue for a longer time in a condition fit for application. The pen should be levelled in the ink, to take up a sufficient charge; and to induce the ink to enter the pen freely, the blades should be lightly breathed upon or wetted before immersion. After each application of ink, the outsides of the blades should be cleaned, to prevent any deposit of ink upon the edge of the squares.

To keep the blades of his *inkers* clean, is the first duty of a draughtsman who is to make a good piece of work. Pieces of blotting or unsized paper, and cotton velvet, washleather, or even the sleeve of a coat, should always be at hand while a drawing is being inked. When a small piece of blotting paper is folded twice so as to present a corner, it may usefully be passed between the blades of the pen, now and then, as the ink is liable to deposit at the point and obstruct the passage, particularly in fine-lining; and for this purpose the pen must be unscrewed to admit the paper. But this process may be delayed by drawing the point of the pen over a piece of velvet, or even over the surface of thick blotting paper; either method clears the point for a time. As soon as any obstruction takes place, the pen should be immediately cleaned, as the trouble thus taken will always improve and expedite the work. If the pen should be laid down for a short time with the ink in it, it should be unscrewed to keep the points apart and so prevent deposit; and when done with altogether for the occasion, it ought to be thoroughly cleaned at the nibs. This will preserve its edges and prevent rusting.

For useful reference, to assist the judgment in the preparation of drawings on paper, the drawing office should be fitted with a vertical scale of full size feet and inches, 6 or 8 feet long, fixed against the wall; and with a horizontal scale the full length of the office, fixed to the wall at 7 or 8 feet above the floor. The scales should be painted conspicuously in white, with black lining and figures.

PART THIRD.

STEREOGRAPHY—DESCRIPTIVE CARPENTRY.

PROJECTION.

Projection has for its object the representing on a given surface the forms of such solid bodies as can have their boundaries properly defined.

Since the surfaces of all bodies may be supposed to consist of points, it is obvious that if the means of determining the position of any one point be possessed, the means of determining the position of all the points are equally possessed, and these will produce the surfaces to which they belong.

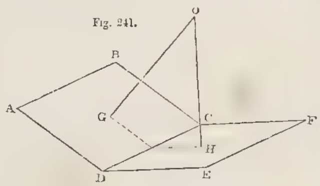
As space is unlimited, the position of a point can only be defined by referring it to some other object or objects whose positions are known. Therefore, if it is required

to convey the knowledge of the position of a point, it is necessary to assume some objects of correlation, the positions of which are known or may be imagined, and planes are the objects generally selected.

Now, suppose a line to pass through the point to be determined, and to be somewhere intersected at a given angle by a plane whose position is known. This intersection will be a point. If the plane and the point of intersection be given, it is clear that the line which passes through the point sought may be drawn. The point sought must be somewhere in that line. But to fix its locality another element is required, and is obtained by supposing another plane intersecting another straight line passing through the point. The positions of the two planes and the directions of the lines being known, the position of the point is defined by the intersection of the lines.

Let A B C D (Fig. 241) and D E F C be the two planes, and G O H O the lines, their intersection at O establishes the position of the point.

Fig. 241.

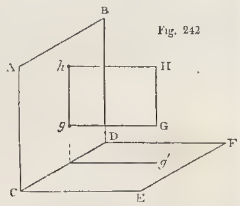


Although the planes may be at any angle in respect of each other, yet in practice, for the sake of simplicity, they are supposed to be at right angles to each other, and the lines passing through the point to be perpendicular to the planes. The intersection of the lines with the planes at G and H are called the projections of the point O.

In order to determine the position of a straight line, it is obviously only necessary to determine any two points in it.

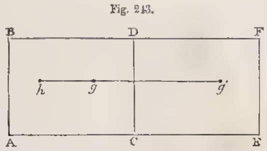
Let G H (Fig. 242) be a straight line, whose position it is required to determine. Let A B C D be a vertical, and E F D C a horizontal plane, then the position of the point G will be determined by its projections g G g' G, and the position of the point H by its projections h H g' H, and, consequently, the position of the line H G is determined; and if the points H G are at the extremities of the line, its length also is determined.

Fig. 242



The planes are here shown in perspective, but in practice they are drawn geometrically on the paper, as if they were supposed to be hinged at C D and laid flat, and in this position they are represented in Fig. 243. It is obvious that all that is required in working the problem is the line of intersection C D.

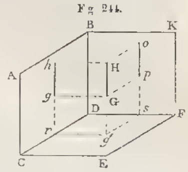
Fig. 243.



As, however, it will facilitate the comprehension of the subject, the projections are shown both in perspective and geometrically.

In the last figure the position of a line was defined by the projections on two planes of two points contained in it. These planes are not the only ones on which the projection may be made. In Fig. 244, $o\,p$ are the projections of the points on a plane B K F D, and in this figure it is seen that $h\ g$ is the projection of the line on the plane A B D C, $o\,p$ is its projection on B K F D, and g' is its projection on C D F E.

Fig. 244.



In Fig. 245 it is shown with the planes laid flat. Omitting the boundary lines, the projection in practice would be as in Fig. 246.

Fig. 245.

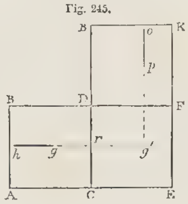
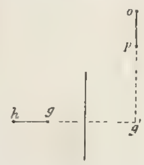


Fig. 246.



By these figures it is made apparent that the drawing of projections is less laborious when the planes are laid flat than if they were vertical; for the vertical and horizontal projections of the line being intersections of the horizontal and vertical planes, by a plane, h H g' r, perpendicular to them both, which passes through the points H G, and which is therefore perpendicular to their intersection C D, the straight lines $g'\ r$, $r\ h$ will also be perpendicular to C D. Hence, if the projection of a point g' on the horizontal plane be known, its projection on the vertical plane laid flat will be in the straight line produced, drawn through g', perpendicular to C D.

The line H G *has been supposed parallel to one of the planes of projection, and its projection on that plane is equal to its length. If the line be oblique to both planes, its length will be greater than either of its projections.*

Let $g\ h\ g'\ h'$ (Fig. 247) be the vertical and horizontal projections of a straight line, its actual length will be greater than either; but the following considerations show that it may be easily found from them. Let a line G K, lying in the plane passing through G H, be drawn through to meet the perpendicular H h' in K, then G K H is a right-angled triangle, of which G H is the hypothenuse: its side K H is equal to the vertical projection $k\ h$, its base to the projection g' h'. Construct this triangle, therefore, as shown in Fig. 248, and $g'\,r$ is the length of the line required. The length may be also found from the vertical projection, thus:—Draw $k\,g$ (Fig. 248) parallel to C D and produce it to s, make $k\ s$ equal to the horizontal projection $h'\ g'$, and join $h\ s$, which will be the length of the line required.

Fig. 247.

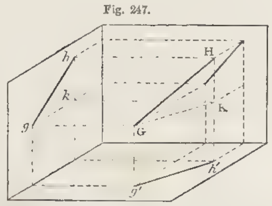
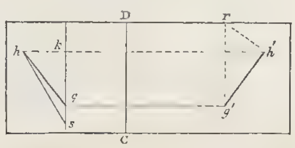


Fig. 248.

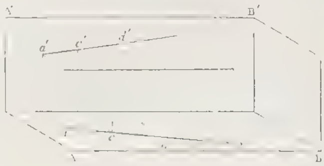


The projections of a right line being given, and a length taken on one of them, to find the original line

which that length represents, and the angle which it makes with each of its planes of projection.

Let $a\ b\ a'\ b'$ (Fig. 249) be the given projections, and $c\ d$ the length, taken on the horizontal projection. As all the points of the line necessarily correspond to all the points of its projection, if on $c\ d$ are raised the indefinite perpendiculars to the common section, these lines will cut the vertical projection $a'\ b'$ in the points c' and d', and $c'\ d'$ will be the length of the vertical projection of $c\ d$.

Fig. 249.



To find the length of the original line: on $c\ d$ (Fig. 250), raise indefinite perpendiculars, upon which from c carry the length 1 c' to C, and from d the length 2 d' to D, and draw through C and D the line A B, which is the original line sought; then through C draw C e parallel to $c\ d$, and the angle D C e is the angle which the original line makes with the horizontal plane. In the same manner the angle with the vertical plane is found on the vertical projection by carrying the length 1 c 2 d from c and d on the perpendiculars $c'\ d'$ to C′ D′, and through C′ and D′, A′ B′, and then from C′, drawing C′ e', parallel to $c'\ d'$, and the angle D′ C′ e' is the angle sought.

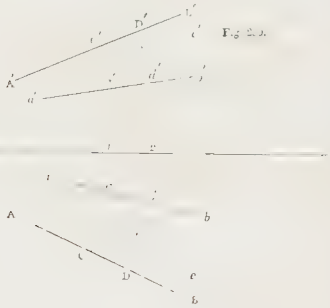
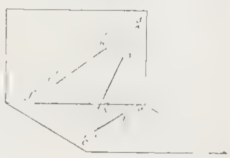


Fig. 250.

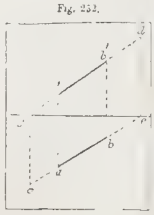
The projections $a'\ b'\ a''\ b''$ (Fig. 251) *of a right line* A B, *being given, to find the points wherein the prolongation of that line would meet the planes of projection.*

Fig. 251.



In the perspective representation of the problem, it is seen that A B, if prolonged, cuts the horizontal plane in c, and the vertical plane in d, and the projections of the prolongation become $c\ e\ f\ d$. Hence, in the following figure, if $a\ b\ a'\ b'$ (Fig. 252) be the projections of A B, the solution of the problem is obtained by producing these lines to meet the common intersection of the planes in f and e, and on these points to raise the perpendiculars $f\ c\ e\ d$, when c and d' are the points sought.

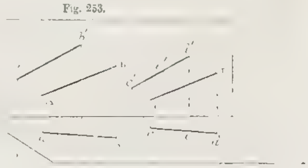
Fig. 252.



To draw through a given point a line parallel to the projections of a given line.

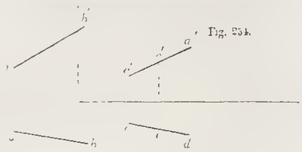
Let $a\ b\ a'\ b'$ (Fig. 253) be the projections of the original line A B. From the perspective representation it is evident that the lines $a\ b\ a'\ b'$ of projections of the planes which pass through the original line A B, and the lines of projection of the planes which pass through any line C D, and parallel to the line A B, are parallel each to each; therefore, if the given point lie in such line C D, the solution of the problem is easy.

Fig. 253.



Let $a\ b\ a'\ b'$ (Fig. 254) be the given projections, and e the given point, then through e draw $c\ d$ parallel to $a\ b$, and through e' draw $c'\ d'$ parallel to $a'\ b'$, and $c\ d\ c'\ d'$ are the projections of the line sought.

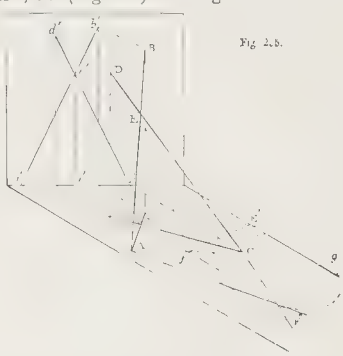
Fig. 254.



If the two lines intersect each other in space, to find from their given projections the angles which they make with each other.

Let A B, C D (Fig. 255) be the given lines intersecting at E. In the perspective representation, if these lines be supposed to lie in a plane which intersects the horizontal plane in the line A C, this line will be the base of a triangle, A E C. If the plane is perpendicular to the horizontal plane, the angle A E C is at once known; but, suppose it inclined to the horizontal plane, then, to find the angle, it is necessary to imagine the plane turned down horizontally on the line A C, as at A E″ C. To do this, from E let fall a perpendicular to the horizontal plane, cutting it in e, which is the horizontal projection of E, and the height e E is the height of the vertex of the triangle above the horizontal plane, and $e\ f$ is the projection of the line E f. There is thus obtained the triangle e E f, which suppose laid horizontally, by turning on its base $e\ f$, then from f as a centre describe the arc E′ g E″, cutting the line $e\ f$ produced in E″, and join A E″ C E″, and A E″ C is the angle sought.

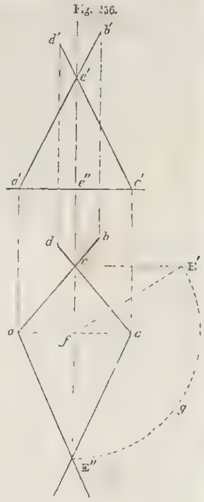
Fig. 255.



In applying this to the solution of the problem, let

$a\ b\ c\ d$, $a'\ b'\ c'\ d'$ (Fig. 256) be the projections of the lines: from e draw indefinitely, $e\ E'$ perpendicular to the line $e' f$, and make $e\ E'$ equal to $e''\ e'$, and draw $f\ E'$: from f as a centre, describe the arc $E'\ g\ E''$, meeting $e\ f$ produced in E'', and join $a\ E''$, $c\ E''$: the angle $a\ E''\ c$ is the angle sought.

Fig. 256.



It will be observed that the projections of the point of intersection of the two lines are in a right line perpendicular to the line of intersection of the planes of projection. Hence this corollary. *The projections of the point of intersection of two lines which cut each other in space, are in the same right line perpendicular to the common intersection of the planes of projection.* This is further illustrated by the next problem.

To determine, from the projection of two lines which intersect each other in the projections, whether the lines cut each other in space or not.

Let $a\ b$, $c\ d$, $a\ b'$, $c\ d'$ (Fig. 257) be the projections of the lines. It might be supposed that as their traces or projections intersect each other, that the lines themselves intersect each other in space, but, on applying the corollary of the preceding problem, it is found that the intersections are not in the same perpendicular to the line of intersection of the planes of projection $a\ c$. This is represented in perspective in Fig. 258.

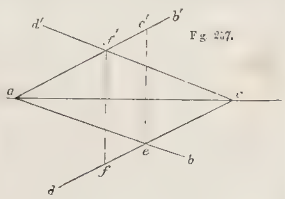


Fig. 257.

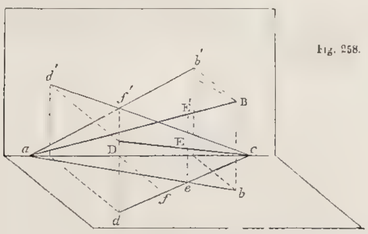


Fig. 258.

We there see that the original lines a B c D do not cut each other, although their projections $a\ b$, $c\ d$, $a\ b'$, $c\ d'$, do so. From the point of intersection e raise a perpendicular to the horizontal plane, and it will cut the original line c D in E, and this point therefore belongs to the line c D, but e belongs equally to a B. As the perpendicular raised on e passes through E on the line c D, and through E′ on the line a B, these points E E′ cannot be the intersection of the two lines, since they do not touch; and it is also the same in regard to $f\ f'$. Hence, when two right lines do not cut each other in space, the intersections of their projections are not, in the same right line, perpendicular to the common intersection of the planes of projection.

The projections of a plane and of a point being given, to draw through the point a plane parallel to the given plane.

In the perspective representation, suppose the problem

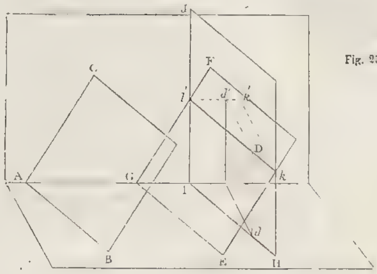


Fig. 259.

solved, and let B C (Fig. 259) be the given plane, and A C, A B its projections, and E F a plane parallel to the given plane, and G F, G E, its projections. Through any point D, taken at pleasure on the plane E F, draw the vertical plane H J, the horizontal projection of which, I H, is parallel to G E. The plane H J cuts the plane E F in the line $k\ l'$, and its vertical projection G F in l'. The horizontal projection of $k\ l'$ is H I, and its vertical projection $k\ l'$; and as the point D is in $k'\ l'$, its horizontal and vertical projections will be d and d'. Therefore, if through d be traced a line d I, parallel to A B, that line will be the horizontal projection of a vertical plane passing through the original point D; and if on I be drawn the indefinite perpendicular I l', and through d', the vertical projection of the given point, be drawn the horizontal line $d'\ l'$, cutting the perpendicular in l', then the line F G drawn through l', parallel to A C, will be the vertical projection of the plane required; and the line G E drawn parallel to A B, its horizontal projection. Hence, *all planes parallel to each other have their*

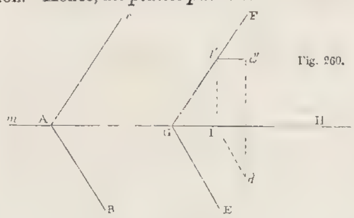


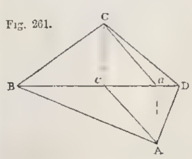
Fig. 260.

projections parallel and reciprocally. In solving the problem, let A B, A C (Fig. 260) be the projections of the given plane, and $d\ d'$ the projections of the given point. Through d draw d I parallel to A B, and from I draw I l' perpendicular to A H: join $d\ d'$, and through d' draw $d'\ l'$ parallel to A H. Then F l' G drawn parallel to A C, and G E parallel to A B, are the projections required.

The projections A B, B C, *and* A D, D C, *of two planes which cut each other being given, to find the projection of their intersections.*

The planes intersect each other in the straight line A C

Fig. 261.



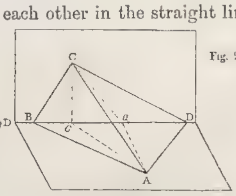


Fig. 262.

(Figs. 261 and 262), of which the points A and C are the

projections, since in these points this line intersects the planes of projection. Now, to find these projections, it is only necessary to let fall on the line of intersection the perpendiculars A a, C c (Fig. 261), from the points A and C, and join A c, C a: A c will be the horizontal projection, and C a the vertical projection of C a (Fig. 261), or C A (Fig. 232), the line of intersection or arris of the planes.

The projections of two intersecting planes being given, to find the angle which they make between them.

The angle formed by two planes is measured by that of two perpendiculars drawn through the same point of their intersections in each of the two faces. These lines determine a third plane perpendicular to the arris. If, therefore, the two planes are cut by a third plane, the solution of the problem is obtained.

On the arris A C (Fig. 263), take at pleasure any point

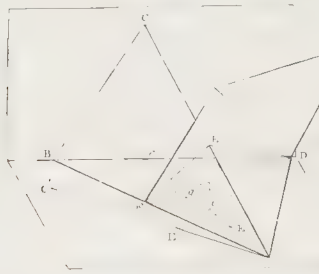


Fig. 263.

E, and suppose a plane passing through that point, cutting the two given planes perpendicular to the arris. There results from the section a triangle D E F, inclined to the horizontal plane, and the angle of which, D E F, is the measure of the inclination of the two planes. The horizontal projection of that triangle is the triangle D e F, the base of which, F D, is perpendicular to A c, and cuts it in the point g, and the line E g is perpendicular to D F. The line g E is necessarily perpendicular to the arris A C, as it is in the plane D E F, and its horizontal projection is g e. Now, suppose the triangle D E F turned on D F as an axis, and laid horizontally, its summit will then be at E″, and D E″ F is the angle sought. The perpendicular g e

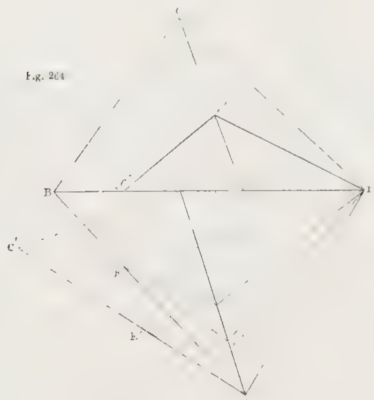


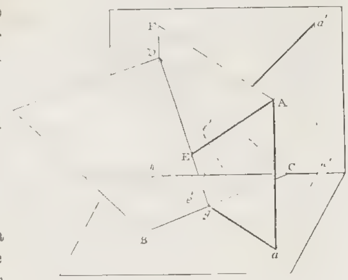
Fig. 264

is also in the vertical triangle A C c, of which the arris is the hypothenuse, and the sides A c, C c, are the projections. This description introduces the solution of the problem, which applies also to Fig. 264.

Through any point g (Fig. 264) taken at pleasure, on the line A c, the horizontal projection of the arris a C, draw F D perpendicular to A c; from g draw g E′ perpendicular to the arris A C′; and from g as a centre, with the radius g E′, describe the arc E′ E″: join F E″, D E″. The angle E″ F D is the angle sought.

Through the projection of a given point $a a'$, to draw a perpendicular to a plane, B C, C D, *also given.*

Fig. 265.

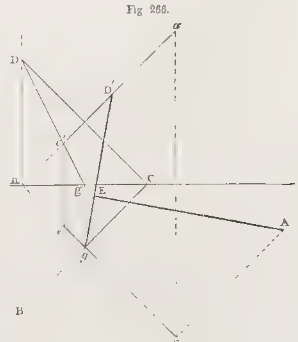


Let A E (Fig. 265) be the perpendicular drawn through the point A to the plane B D, and its intersection with the plane is the point E.

Suppose a vertical plane a F to pass through A E, this plane would cut B D in the line g D, and its projection a h would be perpendicular to the projection B C. In the same way $a'e'$, the vertical projection of A E, would be perpendicular to C D, the vertical projection of the plane B D. Then, if a line, perpendicular to a h, is drawn through a, it will be the horizontal projection of the plane passing in the line of the perpendicular A E, and h F will be its vertical projection. From a', draw upon C D an indefinite perpendicular, and that line will contain the vertical projection of A E, as a h contains its horizontal projection. Now, to find the point of intersection of the line A E with the plane, construct the vertical projection of the line of intersection of the two planes g D, and the point of intersection of that line with the right line drawn through a', will be the point sought. If from that point a perpendicular is let fall on a h, the point e will be the horizontal projection of the point of intersection E.

In Fig. 266, let B C, C D be the projections of the given plane, and a a' of the given point. From the given point a, draw a g perpendicular to B C, which will be the horizontal projection of a plane passing vertically through a, and cutting the given plane. From a, also draw a A perpendicular to a g, and make it equal to a'' a' (Fig. 265). From h draw

Fig 266.



h D′ perpendicular to h a, and make h D′ equal to h D. Draw g D′, which will be the section of the given plane, and the angle h g D′ will be the measure of the inclination of the given plane with the horizontal plane. There is now to be drawn, perpendicular to this line, a line A E

through A, which will be the line required. From the point of intersection E let fall upon $a\,h$ a perpendicular, which will give e as the horizontal projection of E. Therefore:—

Where a right line in space is perpendicular to a plane, the projections of that line are respectively perpendicular to the projections of the plane.

Through a given point $a\,a'$, to draw a plane perpendicular to a right line $b\,c$, $b'\,c'$ also given.

The foregoing problem has shown that the projections of the plane sought must be perpendicular to the projections of the line.

The plane D E (Fig. 267), is, by construction, perpendicular to the line B C. Take at pleasure the point A in the plane D E, and through it draw the horizontal line A f',

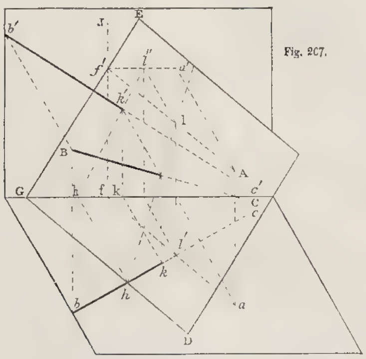


Fig. 267.

which will be necessarily parallel to the projection D G. and will cut the vertical projection G E in f'. The horizontal projection of the intersecting point will be f, that of A will be a, and that of A f' will consequently be a f, which, being parallel to D G, will be perpendicular to $b\,c$. The solution of the problem consists in making to pass through A a vertical plane A f, the horizontal projection of which will be perpendicular to $b\,c$.

Through a (Fig. 268), draw the projection a f perpendicular to $b\,c$: from f raise upon K L the indefinite perpendicular f f', which will be the vertical projection of the plane a f f', perpendicular to the horizontal plane, and passing through the original point A (Fig. 267). Then draw through a' in the vertical projection a horizontal line, cutting $f\,f'$ in f', which point should be in the projection of the plane sought; and as that plane must be perpendicular to the vertical projection of the given right line, draw through f' a perpendicular to $b'\,c'$, and produce it to cut K L in G. This point G is in the horizontal projection of the plane sought. All that remains, therefore, is from G to draw G D perpendicular to $b\,c$. If the projections of the straight line are required, proceed as in the previous problem, and as shown by the dotted lines.

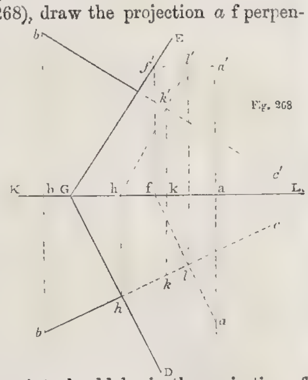


Fig. 268

A right line, $a\,b$ and $a'\,b'$, being given in projection, and also the projection of a given plane, to find the angle which the line makes with the plane.

Let A B (Fig. 269), be the original right line intersecting the plane C E in the point B. If a vertical plane pass through the right line, it will cut the plane C E in the line f B, and the horizontal plane in the line $a\,b$. As the plane a B is in this case parallel to the vertical plane of projection, its projection on that plane will be a quadrilateral figure a b', of the same dimensions; and f B contained in the rectangle will have for its vertical projection a right line D b', which will be equal and similar to f B. Hence the two angles, $a'\,b'$ D, A B f, being equal, will equally be the measure of the angle of inclination of the right line A B to the plane C E. Thus the angle $a'\,b'$ D (Fig. 270) is the angle sought.

Fig. 269.

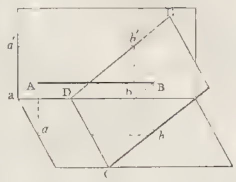
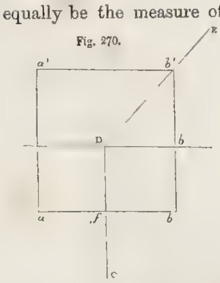


Fig. 270.



This case presents no difficulty; but when the line is in a plane which is not parallel to the plane of projection, the problem is more difficult.

In Fig. 271, the right line A B is oblique to the plane

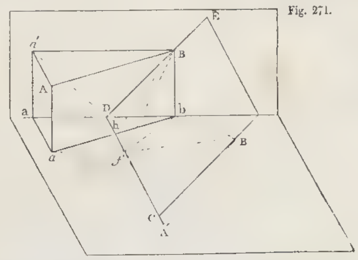


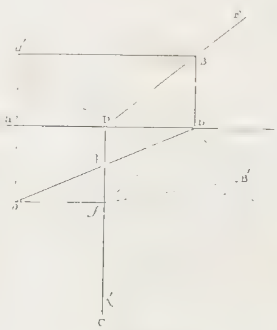
Fig. 271.

of vertical projection. It cuts the plane C E in B. Now, a vertical plane may be supposed, as before, to pass through the line A B and to cut the plane C E, and the angle A B h may at first sight be imagined to be the angle sought—that is, the measure of the inclination of A B with the plane C E. But it is not so; for the vertical plane which passes through A B, and contains that angle, is oblique to the plane C E; and its projection $a\,b$ is consequently not perpendicular to the given plane. It is to be recollected that the inclination of a right line to a plane is measured by an angle situated in a plane which shall pass through the right line, and be perpendicular to the plane, which is always possible. If, therefore, a plane perpendicular to C E pass through the right line A B, the projections of the two planes will be perpendicular to each other. Thus $a\,f$ will be perpendicular to C D, and a' D to D E. These planes intersect in the line f B. This line, as well as the original line A B, will, therefore, be in a plane which is perpendicular to the plane C E, and A B f will be the angle sought.

Through any point A in the given line, draw a perpen-

dicular A f upon the plane C E. This line will also be perpendicular to f B, and will be the third side of a triangle A f B, rectangular at f, perpendicular to the plane C E, and inclined to the horizontal plane. The projections of the triangle will be $a\,f\,b$ on the horizontal, and a' D B in the vertical plane. The projections of the triangle being obtained, it is only necessary to develope it on the horizontal plane by turning it down as on a hinge. To do this, observe that the side f B of the triangle A f B rests on the hypothenuse of a right-angled triangle $f\,b$ B, which is vertical or perpendicular to the horizontal plane. Laying down this triangle flat, by making it turn on its base $b\,f$, as on a hinge, it will then appear as $f\,b$ B′, and its hypothenuse will be the side or base of the triangle sought, B f A. It has been seen that A f was perpendicular to f B: raise on f, therefore, perpendicular to f B′, the side A f, which will be f A′; draw the line A′ B′, which will be the hypothenuse of the triangle sought; and the angle f B′ A′ will be the measure of the inclination of the line A B with the plane C E. From the above description, the operation may be performed in Fig. 272, in which C D, D E are the projections of the plane, and $a\,b$, a' B the projections of the line. Through a in the horizontal projection draw $a\,f$ perpendicular to C D, and join $f\,b$. To obtain the development of the triangle D B b, which is in the vertical projection of a right-angled triangle whose base is $f\,b$, imagine this triangle turned down on its base as on a hinge, that is, by construction; make b B′ equal to b B, and perpendicular to $f\,b$, and join f B′. Then to obtain the development of the triangle a' D B, on f draw f A′ perpendicular to f B′, and make it equal to a' D, and join A′ B′. Then the angle f B′ A, is the measure of the inclination of the line A B, on the plane E C.

Fig. 272.



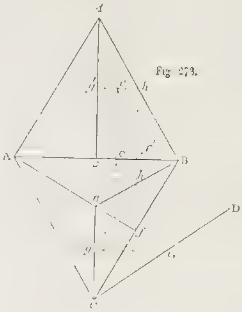
PROJECTIONS OF SOLIDS.

There is no general rule for the projections of solids. Their constructions are more or less easy, dependent on the nature of the question; and it is possible always to accomplish them more or less directly by means of the principles about to be stated.

Given the horizontal projection of a regular tetrahedron, to find its vertical projection.

Let A B C d (Fig. 273) be the given projection of the tetrahedron, which has one of its faces coincident with the horizontal plane. It is evident that the vertical projection of that face will be the line A C B. If the height of d above the horizontal plane be known, it is set off from c to d', and by joining A d', B d', the problem is solved. In proceeding to find the height of d', let us consider that a perpendicular, let fall from the summit of the tetrahedron on the horizontal plane, is also perpendicular to the right lines d A, d B, d C, and forms with each of the arrises a right-angled triangle, of which two of the sides, the right angle, and the direction of the third side, are known. It is easy, therefore, to construct one of those triangles. On d, draw an indefinite line perpendicular to d C, and make C D equal to C B, C A, or A B; d D will be the height sought, which is carried to the vertical projection from c to d'. This problem might be resolved in other ways.

Fig. 273.



A point being given in one of the projections of a tetrahedron, to find the point on the other projection.

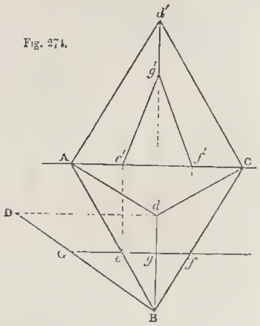
Let e be the point given in the horizontal projection (Fig. 273). It may first be considered as situated in the plane C B d, inclined to the horizontal plane, and of which the vertical projection is the triangle c B d'. According to the general method, the vertical projection of the given point is to be found somewhere in a perpendicular raised on its horizontal projection e. If through d and the point e be drawn a line produced to the base of the triangle in f, the point e will be on that line, and its vertical projection will be on the vertical projection of that line $f'\,e\,d'$, at the intersection of it with the perpendicular raised on e. If through e be drawn a straight line $g\,h$, parallel to C B, this will be a horizontal line, whose extremity h will be on B d. The vertical projection of d B is d' B; therefore, by raising on h a perpendicular to A B, there will be obtained h', the extremity of a horizontal line represented by $h\,g$ in the horizontal plane. If through h' is drawn a horizontal line $h'\,g'$, this line will cut the vertical line raised on e in e', the point sought. If the point had been given in g on the arris C d, the projection could not be found in the first manner; but it could be found in the second manner, by drawing through g a line parallel to C B, and prolonging the horizontal line drawn through h to the arris C d', which it would cut in g', the point sought. The point can also be found by laying down the rectangular triangle C d D, which is the development of the triangle formed by the projection of the arris C d, the height of the solid and the length of the arris as a hypothenuse, and by drawing through g the line g G perpendicular to C d, to intersect the hypothenuse in G, and carrying the height g G from c to g, in the vertical projection. Thus, one or other of these means can be employed according to circumstances. If the point had been given in the vertical, instead of the horizontal projection, the same operations inverted would require to be used.

Given a tetrahedron, and the projection of a plane cutting it, by which it is truncated, to find the projection of the section.

First, when the intersecting plane is perpendicular to the base (Fig. 274), the plane cuts the base in two points $e\,f$, of which the vertical projections are e' and f'; and the

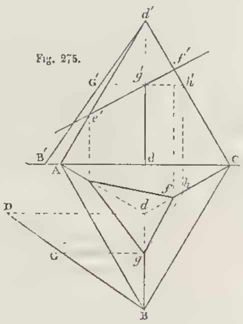
arris B d is cut in g, the vertical projection of which can readily be found in any of the ways detailed in the last problem. Having found g', join $e'\,g'$, $f'\,g'$, and the triangle $e'\,g'\,f'$ is the projection of the intersection sought.

Fig. 274.



When the intersecting plane is given in the vertical projection, as $e'\,f'$ in Fig. 275, the horizontal projections of the three points $e'\,g'\,f'$ have to be found. The point g in this case may be obtained in several ways. First, by drawing G$'$ g' h through g', then through h' drawing a perpendicular to the base, produced to the arris at h, in the horizontal projection, and then drawing $h\,g$ parallel to C B, cutting the arris B d in g, which is the point required. Second, take d B as the base of a triangle formed by the perpendicular, and the arris of which, d B, is the horizontal projection, and carry this base, d B, upon the common line of intersection of the planes from d to B$'$, and draw the arris B$'$ d'. From g' draw the horizontal line cutting B$'$ d' in G$'$; carry g' G$'$, which is the distance of the perpendicular of the arris in the horizontal projection, from d to g; and g is the point sought.

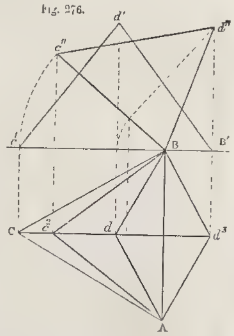
Fig. 275.



The projections of a tetrahedron being given, to find its projections when inclined to the horizontal plane in any degree.

Let A B C d (Fig. 276) be the projections of a tetrahedron, with one of its sides coincident with the horizontal plane, and $c'\,d'$ B$'$ its vertical projection; it is required to find its projections when turned round the arris A B as an axis.

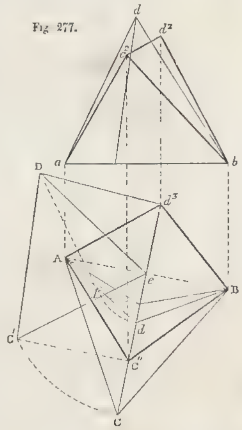
Fig. 276.



The base of the pyramid being a triangle, its vertical projection is the right line c' B. If this line is raised to c'', by turning round B, the horizontal projection will be A c^2 B. When the point c', by the raising of B c', describes the arc $c'\,c''$, the point d' will have moved to d'', and the perpendicular let fall from that point on the horizontal plane will give d^3, the horizontal projection of the extremity of the arris C d; for as the summit d moves in the same plane as C, parallel to the vertical plane of projection, the projection of the summit will evidently be in the prolongation of the arris C d, which is the horizontal projection of that plane. The process, therefore, is very simple, and is as follows:—Construct at the point B the angle required, c' B c'', and make the triangle c'' B d'' equal to $c'\,d$ B$'$; from d'' let fall a perpendicular cutting the prolongation of the arris $c\,d$ in d^3; and from c'', a perpendicular cutting the same line in c^2; join B c^2, A c^2, B d^3, A d^3.

The following is a more general solution of the problem:—Let A B C d (Fig. 277) be a pyramid resting with one of its sides on the horizontal plane, and let it be required to raise, by its angle C, the pyramid, by turning round the arris A B, until its base makes with the horizontal plane any required angle, as 50°. Conceive the right line C e turning round e, and still continuing to be perpendicular to A B, until it is raised to the required angle. If a perpendicular be now let fall from C$'$, it will give the point C$''$ as the horizontal projection of the angle C in its new position. Conceive a vertical plane to pass through the line C e. This plane will necessarily contain the required angle. Suppose, now, we lay this plane down in the horizontal projection, thus:—Draw from e the line e C$'$, making with e C an angle of 50°, and from e with the radius e C describe an arc cutting it in C$'$. From C$'$ let fall on C e a perpendicular on the point C$''$, which will then be the horizontal projection of C in its raised position. On C$'$ e draw the profile of the tetrahedron C$'$ D e inclined to the horizontal plane. From D let fall a perpendicular on C e produced, and it will give d^3 as the horizontal projection of the summit of the pyramid in its inclined position. Join A d^3, B d^3, A c'', B c'' to complete the figure.

Fig. 277.

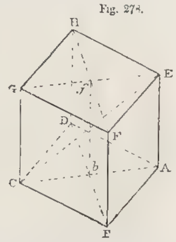


The vertical projection of the tetrahedron in its original position is shown by $a\,d\,b$, and in its raised position by a, c^2, d^2, b.

To construct the vertical and horizontal projections of a cube, the axis of which is perpendicular to the horizontal plane.

The axis of a cube is the straight line which joins two of its opposite solid angles. If an arris of the cube is given, it is easy to find its axis; as it is the hypothenuse of a right-angled triangle, the shortest side of which is the length of an arris, and the longest the diagonal of a side. Conceive the cube cut by a vertical plane passing through its diagonals E G, A C (Fig. 278), the section will be the rectangle A E G C. Divide this into two equal right-angled triangles, by the diagonal E C. If, in the upper and lower faces of the cube, we draw the diagonals F H, B D, they will cut the former diagonals in the points $f\,b$. Now, as the lines b B, b D, f F, f H, are

Fig. 278.



perpendicular to the rectangular plane A E G C, $f\,b$ may be considered as the vertical projection of B F, D H, and from this consideration we may solve the problem.

Let A E (Fig. 279), be the arris of any cube (the letters here refer to the same parts as those of the preceding diagram, Fig. 278). Through A draw an indefinite line, A C, perpendicular to A E. Set off on this line, from A to C, the diagonal of the square of A E, and join E C, which is then the diagonal of the cube. Draw then the lines E G, C G, parallel respectively to A C and A E, and the resulting rectangle, A E G C, is the section of a cube on the line of the diagonal of one of its faces. Divide the rectangle into two equal parts by the line $b\,f$, which is the

Fig. 279.

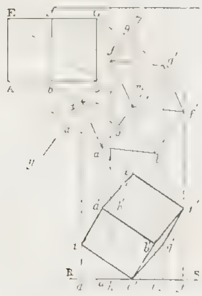
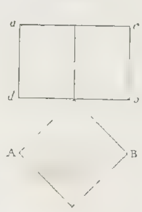


Fig. 280.



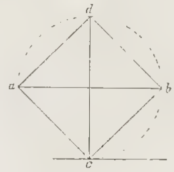
vertical projection of the lines B F, D H (Fig. 278), and we obtain, in the figure thus completed, the vertical projection of the cube, as $a\ c\ b\ d$ (Fig. 280).

Through C (Fig. 279), the extremity of the diagonal, draw $y\,z$ perpendicular to it, and let this line represent the common section of the two planes of projection. Then let us find the horizontal projection of a cube, of which A E G C is the vertical projection. In the vertical projection the axis E C is perpendicular to $y\,z$, and, consequently, to the horizontal plane of projection, and we have the height above this plane of each of the points which terminate the angles. Let fall from each of these points perpendiculars to the horizontal plane, the projections of the points will be found on these perpendiculars.

To find, for example, the horizontal projection of the axis E C, take at pleasure, on its prolongation, any point, C′ (or e), which is the projection of both the extremities of the axis C and E. If we suppose the rectangle A E G C turned on the line $y\,z$ until it is vertical, its projection will be $a\,g$. Through C′ (or e) draw a line parallel to $y\,z$, and find on it the projection of the rectangle $a'\ c'\ g'$, by continuing the perpendiculars A a, G g. We have now to find the projections of the points $b\ f$ (which represent D B F H, Fig. 278), which will be somewhere on the perpendiculars $b\ b'$, $f\,f''$, let fall from them. We have seen in the preceding Fig. (No. 278), that B F, D H are distant from $b\,f$ by an extent equal to half the diagonal of the square face of the cube. Set off, therefore, on the perpendiculars $b\ b'$ and $f'\ f''$, from o and m, the distance A b in $d\ b'$ and $f'\ f''$, and join $d\ a'$, $a'\ b'$, $b'\ f'$, $f''\ g'$, $g'\ f'$, to complete the hexagon which is the horizontal projection of the cube. The dotted lines, d C′, b' C′, g' C′, show the arrises of the lower side. Knowing the heights of the points in these vertical projections, it is easy to construct a vertical projection on any line whatever, as that on R S below. In these figures all the points are indicated by the same letters as in the preceding figures.

To construct the projections of a regular octahedron.—The octahedron is formed by the union of eight equilateral triangles; or, more correctly, by the union of two pyramids with square bases, opposed base to base, and of which all the solid angles touch a sphere in which they may be inscribed.

Fig. 281.

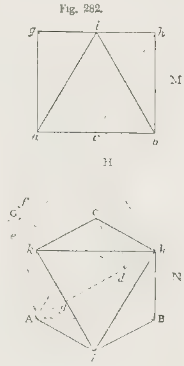


Describe a circle (Fig. 281), and divide it into four equal parts by the diameters, and draw the lines $a\,d$, $d\,b$, $b\,c$, $c\,a$; a figure is produced which serves for either the vertical or the horizontal projection of the octahedron, when one of its axes is perpendicular to either plane.

One of the faces of an octahedron being given, coincident with the horizontal plane of projection, to construct the projections of the solid.

Let the triangle A B C (Fig. 282) be the given face. If A be considered to be the summit of one of the two pyramids which compose the solid, B C will be one of the sides of the base. This base makes, with the horizontal plane, an angle, which is easily found. Let fall from A a perpendicular on B C, cutting it in d. With the length B C as a radius, and from d as a centre, describe the indefinite arc $e\,f$. The perpendicular A d will be the height of each of the faces, and, consequently, of that which, turning on A, should meet the side of the base which has already turned on d. Make this height turn on A, describing from that point as a centre, with the radius A d, an indefinite arc, cutting the first arc in G, the point of meeting of one of the faces with the square base: draw the lines G A, G d: the first is the profile or inclination of one of the faces on the given face A B C, according to the angle d A G; the second, d G, is the inclination of the square base, which separates the two pyramids in the angle A d, d G. The face adjacent to the side B C is found in the same manner. Through G, draw the horizontal line G H equal to the perpendicular A d. This line will be the profile of the superior face. Draw d H, which is the profile of the face adjacent to B C. From H let fall a perpendicular on A d produced, which gives the point h for the horizontal projection of H, or the summit of the superior triangle parallel to the first: draw $i\,k$, k C, C h, h B, $h\,k$, $h\,i$, and the projection is obtained. From the heights we have thus obtained, we can now draw the vertical projection M, in which the parts have the same letters of reference.

Fig. 282.

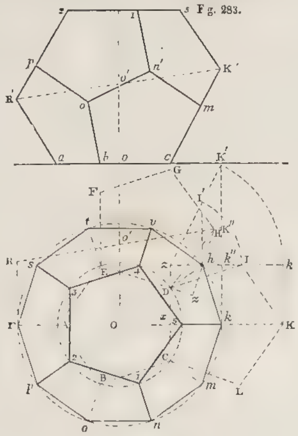


The finding the horizontal projection may be abridged by constructing a hexagon in which may be inscribed the two triangles A C B, $h\ i\ k$ (Fig. 282 N), and the projection is completed.

Given in the horizontal plane the projection of one of the faces of a dodecahedron, to construct its projections.

The dodecahedron is formed by the assemblage of twelve regular and equal pentagons. It is necessary, in order to construct the projection, to discover the inclination of the faces among themselves. Let the pentagon A B C D E (Fig. 283) be one of the faces on which the body is supposed to be seated on the plane. Conceive two other faces, E F G H D, D I K L C also in the horizontal plane, and then raised by being turned on their bases, E D, D C. By their movement they will describe in space arcs of circles, which will terminate by the meeting of the sides D H, D I.

Fig. 283.



To find the inclinations of these two faces.—From the points I and H let fall perpendiculars on their bases produced. If each of these pentagons were raised vertically on its base, the horizontal projections of H and I would be respectively in z z; but as both are raised together, the angles H and I would meet in space above h, where the perpendiculars intersect, therefore, h will be the horizontal projection of the point of meeting of the angles. To find the horizontal projection of G o K, prolong indefinitely z I, and set off from z on z I the length x K in k'; then from z as a centre, with the radius $z\,k$, describe an arc cutting z I′ produced in the point K′, from which let fall on $z\,k'$ a perpendicular K′ k'', and produce it to x K. If, now, the right-angled triangle, $z\,k''$ K′, were raised on its base, k'' would be the projection of K′. Conceive now the pentagon C D I K L turned round on C D, until it makes an angle equal to $k''\,z$ K′ with the horizontal plane, the summit K will then be raised above k by the height k'' K′, and will have for its projection the point k. In completing the figure practically;—from the centre o, describe two concentric circles passing through the points h D. Draw the lines h D, $h\,k$, and carry the last round the circumference in $m\ n\ o\ p\ r\ s\ t\ v$: through each of these points draw radially the lines m C, o B, r A, t E, and these lines will be the arrises analogous to h D. This being done, the moiety or inferior half of the solid is projected. By reason of the regularity of the figure, it is easy to see that the six other faces will be similar to those already drawn, only that although the superior pentagon will have its angles on the same circumference as the inferior pentagon, the angles of the one will be in the middle of the faces of the other. Therefore, to describe the superior half;—through the angles $n\ p\ s\ v\ k$, draw the radial lines n 1, p 2, s 3, v 4, k 5, and join them by the straight lines 1 2, 2 3, 3 4, 4 5, &c.

To obtain the length of the axis of the solid, observe that the point k is elevated above the horizontal plane by the height k'' K′: carry that height to k K″: the point r, analogous to h, is raised by the same height as that point, that is to say h I′, which is to be carried from r to R; and the line R K″ is the length sought. As this axis should pass through the centre of the body, if a vertical line O O′ is drawn, it will cut the vertical projection of the axis in O′, and therefore O O′ is the half of the height of the solid vertically. By doubling this height, and drawing a horizontal line to cut the vertical lines of the angles of the superior pentagon, the vertical projection of the superior face is obtained, as in the upper portion of Fig. 283, in which the same letters refer to the same parts.

One of the faces of a dodecahedron, A B C D E (Fig. 284), *being given, to construct the projections of the solid, so that its axis may be perpendicular to the horizontal plane.*

The solid angles of the dodecahedron are each formed by the meeting of three pentagonal planes. If there be conceived a plane passing through the extremities of the arris of the solid angle, the result of the section would be a triangular pyramid, the sides of whose base would be equal to one of the diagonals of the face, such as B C (Fig. 284). An equilateral triangle $b\,c\,f$ (Fig. 285), will represent the base of that pyramid inverted, that is, with its summit resting on the horizontal plane. In constructing the projection, it is required to find the height of that pyramid, or, which is the same thing, that of the three points of its base $b\,c\,f$, for as they are all equally elevated, the height of one of them gives the others. There is necessarily a proportion between the triangle A b c (Fig. 285) and A B C (Fig. 284), since the first is the horizontal projection of the second. A g is the projection of A G; but A G is a part of A H, and the projection of that line is required for one of the faces of the solid; therefore, as A G: A g:: A H: x, which may be found, by seeking a fourth proportional, to be equal to A h; or graphically thus:—Raise on A g at g an indefinite perpendicular, take the length A G (Fig. 284) and carry it from A to G′ (Fig. 285), g being one of the points of the base, elevated above the horizontal plane by the height g G′; its height giving also the heights of $b\,c\,f$. Since A G is a portion of A H, A G′ will be so also. Produce A G′, therefore, and carry on it A H (Fig. 284) from A to H′, and from H′ let fall a perpendicular on A g produced, which gives h the point sought. Produce H′ h, and carry on it the length H D or H E from h to d and h to e; draw the lines $c\,d$, $b\,e$,

Fig. 286.

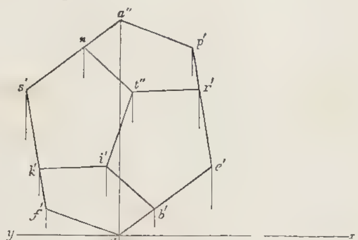


Fig. 285.

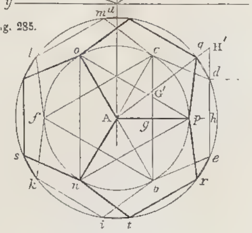
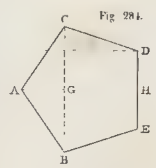


Fig. 284.



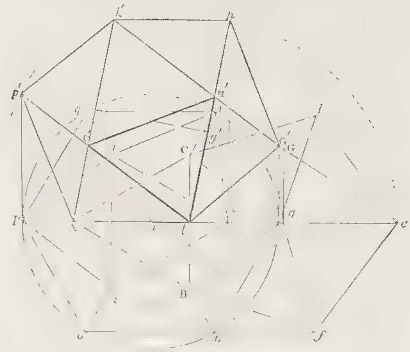
and the projection of one of the faces is obtained inclined to the horizontal plane, in the angle H′ A h. As the two other inferior faces are similar to the one found, the three faces should be found on the circumference of a circle traced from A as a centre, and with A d or A e as a radius. Prolong A n, A o, perpendiculars to the sides of the triangle, and make them equal to A h, and through their extremities draw perpendiculars, cutting the circumference in the points $i\,k$, $l\,m$. Through these points draw the lines $i\,b$, $k\,f$, $l\,f$, $m\,c$, and the projections of the three inferior faces are obtained. The superior pyramid is similar and equal to the inferior, and solely opposed by its angles. Describe a circle passing through the three points of the first triangle, and draw within it a second equilateral triangle $n\,o\,p$, of which the summits correspond to the middle of the faces of the former one. Each of these points will be the summit of a pentagon, as the points $b\,c\,f$. These pentagons have all their sides common, and it is only necessary therefore to determine one of these superior pentagons to have all the others.

To obtain the vertical projection (Fig. 286), begin with the three inferior faces. The point A in the horizontal projection being the summit of the inferior solid angle, will have its vertical projection in a: the points $b\,c\,f$, when raised to the height g G′, will be in $b'\,c'\,f'$, or simply $b'\,f'$. The points $b\,g\,c$ being in a plane perpendicular to the vertical plane, will be necessarily confounded with each other. The line $a\,f'$ will be the projection of the arris A f, and $a\,b'$ will be that of the arrises A b, A c, and line A g, or rather that of the triangle A $b\,c$, which is in a plane perpendicular to the vertical plane. But this triangle is only a portion of the pentagonal face of the solid originally given, and of which A H is the perpendicular let fall from A on the side E D (Fig. 284). This side is common to the inferior pentagon, and to the superior pentagon $e\,d\,q\,p\,r$, which is also perpendicular to the vertical plane; and, consequently, its vertical projection will be $e'\,p'$, equal to $a\,e'$. This projection can be now obtained by raising a vertical line through p, the summit of the superior pentagon, and from e' as a centre, and with the radius A H′ or A H, describing an arc cutting this line in p', the point sought. But $p\,n\,o$ belong to the base of the superior pyramid; therefore, if the height p' is transferred to n', by drawing through p' a line parallel to $y\,x$, n' will be the projection of the points n and o. Through n' draw $s'\,n'\,a'$ parallel to $a\ e'$, cutting perpendiculars drawn through s and A in the horizontal projection. Through s' draw $s'\,f'$ parallel to $p'\,e'$, and join $a\ f'$, $a'\,p'$; set off on the perpendicular from r the height of s' above $y\,z$ at r', and draw $r'\,t'$ parallel to $y\,z$, cutting the perpendicular from t, and join $n'\,t'$. Make k' and i' the same height as e', and draw $k'\,i'$, and join $i'\,b'$, $i'\,t'$; and we obtain the projection sought.

One of the faces of an icosahedron being given, to construct the projections of the solid when the given face coincides with the horizontal plane of projection.

Let the triangle A B C (Fig. 287) be the given face. It may be observed that B C is one of the sides of the base of a pentagonal pyramid. Conceive this base turned on B C and laid in the horizontal plane, it will then be the pentagon B C $d\,e\,f$. To the centre g, draw the lines B g, C g, $d\ g$, $e\ g$, $f\,g$, and the horizontal projection of the pyramid is obtained. Conceive now the pyramid raised by turning round B C, and its summit e stopped when it has

Fig. 287.



met the point h, one of the summits of the superior triangles of the solid, and it will by construction be confounded with that point. Then, if on h is raised an indefinite perpendicular, and from the centre l, with the radius $l\,e$, an arc is described cutting the perpendicular in the point h', the line $h\,h'$ will be the height of the summit of the pentagon, the base of the pyramid; and the line $l\,h'$ will be the vertical projection or profile of $l\,e$. When $l\,e$, in being raised, described the arc $e\,h'$, $l\,g$ has described the arc $g\,g'$, and the last point g' will, therefore, be the vertical projection of the centre of the pentagonal base, or the extremity of the perpendicular let fall from the summit of the pyramid on that base. Now, this perpendicular is a portion of the axis of the icosahedron; therefore, if through g' an indefinite line perpendicular to $l\,h$ be drawn, that line will be the direction of the axis of the solid, and its length has now to be determined to define the summits of the two opposite pyramids. As the pentagonal pyramid is placed with its summit in the horizontal plane, its base must be necessarily raised above that plane by the height of the perpendicular let fall from its summit upon that base in g, as g G, and this length, g G, is now to be set off in the direction of the axis from g' to G′; then drawing G′ l, G h', a portion of the projection is obtained. From m as a centre, and with $m\,g$ as a radius, describe a circle, in the circumference of which will be found the projections of the summits of five other pentagonal pyramids, equal and similar to the first. To find these:—Through f and d draw lines parallel to $l\,e$, cutting the circumference in $n\ o\ r\ q$, or rather through the summits of the opposite triangles; and to the centre m draw portions of radii B n, $k\,o$, A p, $i\,q$, C r; and through each of the points draw perpendiculars cutting the axis in p', and the lines A k', $l\,h'$, in $o'\,n'$; and through these points draw the lines shown in the figure, and the projection is complete.

Fig. 288.

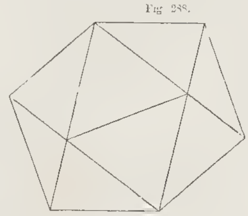
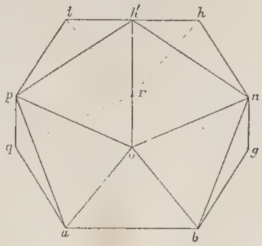


Fig. 288 shows this projection freed from the lines of construction.

Having found the heights of the different points, the

projection in Fig. 289, which is on a line parallel to $a\ b$, can be easily made.

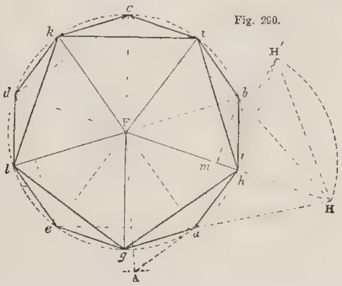
Fig. 289.



A side or an arris of an icosahedron being given, to construct the projections of the solid, so that one of its axes may be perpendicular to the horizontal plane.

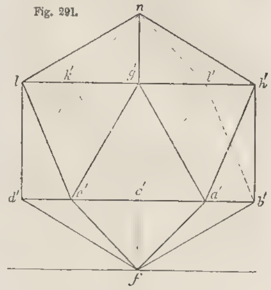
As in the preceding example of the pentagonal pyramid $a\ b\ c\ d\ e$ (Fig. 290), placed on its summit F on the horizontal plane,

Fig. 290.



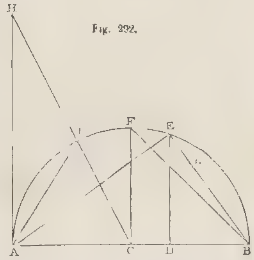
let the side be considered as the given side of the solid. Observe that the superior part of the solid is also a pyramid $g\ h\ i\ k\ l$, equal and similar to the first, but having its angles in the centres of the sides thereof. Thus, there will be for the horizontal projections of these pyramids two pentagons, the arrises of which will be represented by lines drawn from each angle to the centre. Observe further, that the two pyramids are separated by ten triangles, which have a certain inclination to each other, and alternately in an inverse order; and that the height of these triangles added to the height of the two pyramids is the length of the axis. As all the triangles have their sides common, the side $a\ b$ may be considered as the side or base of the triangle a H b, laid on the horizontal plane. Conceive this triangle raised by turning it round $a\ b$ until its summit meet h, one of the angles of the base of the superior pyramid. To find its inclination, from H let fall on the base the perpendicular Hm, and draw through h the line h H′, perpendicular to H h; then from m as a centre, with the radius m H, describe an arc cutting h H′ in H′, and join m H′: the line m H′ will then be the profile or inclination of the face of the triangle $a\ b$ H, according to the angle H m H′; and the projection of the summit is h. By drawing the lines $h\ a$, $h\ b$, the projection of the triangle a H b, inclined to the horizontal plane in $a\ h\ b$, is obtained, and the line h H′ will be the length of the portion of the axis comprised between the bases of the two pyramids. To find the height of the base of the lower pyramid above the horizontal plane:—As all its angles or points are equally elevated, any of them may be taken indifferently, as a. Whatever be the height of this point, such height will always be the side of a right-angled triangle, of which F a is the other side; and the arris, of which F a is the projection, is the hypothenuse. Consequently, if from a is raised an indefinite line a A, perpendicular to F a, and upon it is set off the length of any of the arrises, such as $a\ b$, from F to A, the height a A will be the height sought. Thus, having obtained the data for constructing the vertical projection, it may be proceeded with as follows:—Through f (Fig. 291) draw the line $f\ c'\ g'\ n$ corresponding to the axis, and on it set up the heights $f\ c'$ equal to a A, $c'\ g'$ equal to h H′, and $g'\ n$ equal to a A. Through c' and g' draw lines parallel to the horizontal plane, and on these find the points d', e', a', b', and l, k', l', h', by drawing perpendiculars from the points in the horizontal projection, and join these by lines, as in the figure.

Fig. 291.



To inscribe these five solids in the same sphere, proceed as follows:—Let A B (Fig. 292) be the diameter of the given sphere: divide it in three equal parts, and make D B equal to one of them: draw D E perpendicular to A B, and draw the chords A E, E B. A E is the arris of a tetrahedron, and E B the arris of a hexahedron or cube. From the centre C draw the perpendicular radius C F, and the chord F B is the arris of the octahedron. Divide B E in extreme and mean proportion in G, and B G is the arris of the dodecahedron. Lastly, make the tangent A H equal to A B, draw C H, and the chord A I is the arris of the icosahedron.

Fig. 292.

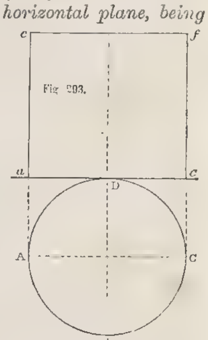


THE THREE CURVED BODIES—THE CYLINDER, THE CONE, THE SPHERE.

1.—*The horizontal projection of a cylinder, the axis of which is perpendicular to the horizontal plane, being given, to find the vertical projection.*

Let the circle A B C D (Fig. 293), be the base of the cylinder, and also its horizontal projection: from the points A and C raise perpendiculars to the horizontal plane $a\ c$, and produce them to the height of the cylinder—say, for example, $a\ e$, $c\ f$: draw $e\ f$, and the rectangle $a\ e\ f\ c$ is the projection required.

Fig. 293.

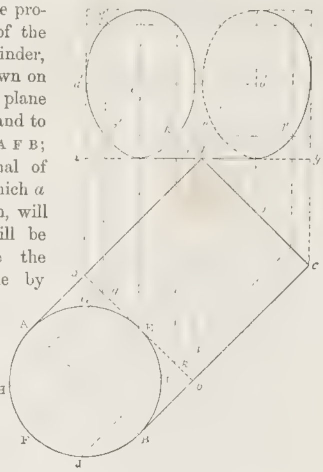


2.—*The horizontal projection of a cylinder, whose axis is parallel to the horizontal plane, being given, to construct its vertical projection.*

Let the rectangle $a\ c$ (Fig. 294) be the given projection. From each of the points a, b, c, d, draw perpendiculars to

$x\,y$: on $x\,y$ set off the height, which of course equals the diameter; and through the points obtained draw a line parallel to $x\,y$. Conceive $a\,b$, the projection of one of the bases of the cylinder, to be turned down on the horizontal plane on the point E, and to be a circle E A F B; then the original of the point, of which a is the projection, will be A, which will be elevated above the horizontal plane by the height a A. To obtain the vertical projection of a or A, therefore, it is only necessary to carry from x to a', on the perpendicular passing through a, the height a A. In the same way is found the vertical projection of any point in the base, as g: from g draw perpendicular to $a\,b$ a line cutting the circle in G and H. Draw also from g to the vertical projection the line $g\,g'\,h'$, and set on it the height g G, g H, in g' and h', which are the vertical projections of g. Thus any number of points may be found, and a curve traced through them. It is evident that as the base $d\,c$ is similar and equal to $a\,b$, its projections will also be similar and equal.

Fig. 294.



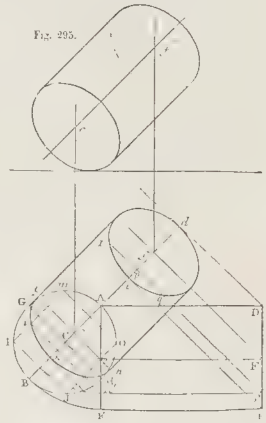
These circular bases being in planes which are not parallel to the vertical plane, their projections are ellipses, the two axes of which can always be readily found, and the operation of projecting them may thus be shortened.

In surfaces of revolution, any point on the surface belongs equally to the generating line, and to the generating circle; consequently, if it be required to find the projection of a point on the surface of a cylinder, it is only necessary to draw a line through the point parallel to the sides of the cylinder, cutting the line of projection of one or both of its bases; to draw, from these intersections, lines cutting the ellipses in the vertical projection; and from these the projection of the line passing through the point, and consequently the projection of the point itself, is easily found. Let i be the point; through it draw $k\,i\,l$, cutting the base or horizontal projection of the generating circle in k and l; through k draw $k\,k'$, and through l draw $l\,l'$, and join $k'\,l'$, and the intersection of the lines $k'\,l'$, $i\,i''$, in the vertical projection, defines the point. But it can also be found without referring to the intersections, thus:—Through the point i, draw $i\,k$, I J, parallel to $b\,c$, and through it draw also $i\,i'$ perpendicular to $x\,y$; then on the last line set up the height $k\,i$, which will give the plane of the point in $i''\,i$.

The horizontal projection of the base of a cylinder being given, and also the angle which the base makes with the horizontal plane, to construct the projections of the cylinder.

Let the circle A G B H (Fig. 295) be the given base, and let the given angle be 45°. Draw the line A B′, making with A B the given angle; and from A as a centre, with A B and A C as radii, describe arcs cutting A B′ in B′ and C′. Then draw A D, B′ E, perpendicular to A B′, and equal to the length of the cylinder; and the rectangle A E is the profile of the cylinder inclined to the horizontal plane in an angle of 45°. Now prolong indefinitely the diameter B A, and this line will represent the projection on the vertical plane of the line in which the generating circle moves, to produce the cylinder. If from B′ and C′ perpendiculars be let fall on A B, k will be the horizontal projection of B′ A k of the diameter A B, and c of the centre C. Through c draw $h\,g$ perpendicular to A B, and make $c\,h$, $c\,g$, equal to C H, C G; and the two diameters of the ellipse, which is the projection of the base of the cylinder, will be obtained.

Fig. 295.



In like manner, draw from D F E the lines D d, F f, E e, perpendicular to the diameter A B produced, and their intersections with the diameter and the sides of the cylinder will give the means of drawing the ellipse which forms the projection of the further end of the cylinder. The ellipses may also be found by taking any number of points in the generating circle as I J O m, and obtaining their projections i, j, r, q. The method of doing this will be seen by the figure without further explanation.

Of the Sections of the Cylinder by a Plane.

A cylinder may be cut by a plane in three different ways—1st, the plane may be parallel to the axis—2d, it may be parallel to the base—3d, it may be oblique to the axis or the base.

In the first case, the section is a parallelogram, whose length will be equal to the length of the cylinder, and whose width will be equal to the chord of the circle of the base in the line of section. Whence it follows, that the largest section of this kind will be that made by a plane passing through the axis; and the smallest will be when the section plane is a tangent—the section in that case will be a straight line.

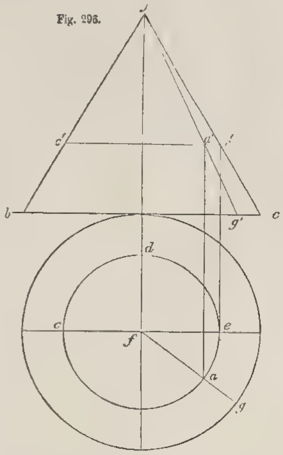
When the section plane is parallel to the base, the section will be a circle equal to the base. When the section plane is oblique to the axis or the base, the section will be an ellipse. As the manner of constructing the ellipse produced by the section of the cylinder has been already treated of, and it will again come under consideration when treating of the sections of solids, it is not necessary here to dilate further on the subject.

PROJECTIONS OF THE CONE.

A point in one of the projections of a cone being given, to find it in the other projection.

Let a (Fig. 296) be the given point. This point belongs equally to the circle which is the section of the cone by a plane parallel to the base, and to a straight line forming one of the sides of a triangle which is the section of the cone by a plane perpendicular to its base and passing through its vertex, and of which $f\,a\,g$ is the horizontal, and $f'\,a'\,g'$ the vertical projection. To find the vertical projection of a, therefore, when the horizontal projection is given, through a draw $a\,a'$ perpendicular to $b\,c$, and its intersection with $f'\,g'$ is the point required; and reciprocally, a in the horizontal projection may be found from a' in the vertical projection, in the same manner.

Fig. 296.



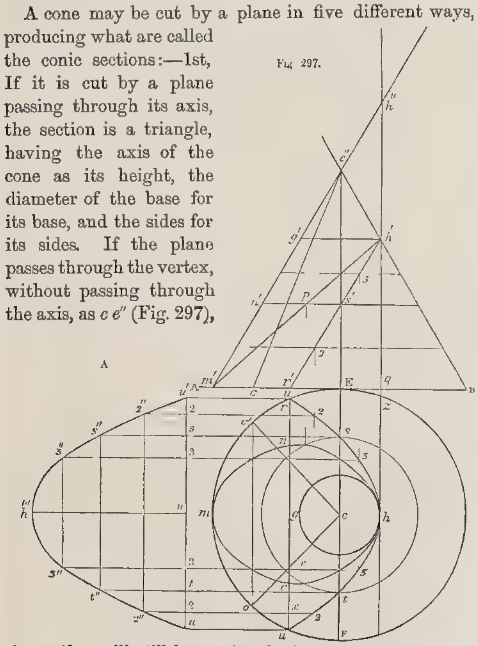
Otherwise, through a, in the horizontal projection, describe the circle $a\,d\,c$, and draw $e\,e'$ or $c\,c'$, cutting the sides of the cone in e' and c; draw $c'\,e'$ parallel to the base, and draw $a\,a'$, cutting it in a', the point required.

Of the Sections of a Cone by a Plane.

A cone may be cut by a plane in five different ways, producing what are called the conic sections:—1st, If it is cut by a plane passing through its axis, the section is a triangle, having the axis of the cone as its height, the diameter of the base for its base, and the sides for its sides. If the plane passes through the vertex, without passing through the axis, as $c\,e''$ (Fig. 297),

Fig. 297.

A



the section will still be a triangle, having for its base the chord $c'\,o$, for its height the line E e'', and for its sides the sides of the cone, of which the lines $c'\,e$, $o\,e$, are the horizontal, and the line $c\,e''$ the vertical projections. 2d. If the cone is cut parallel to the base, as in $g'\,h'$, the section will be a circle, of which $g'\,h'$ will be the diameter. 3d. When the section plane is oblique to the axis, and passes through the opposite sides of the cone, as $m'\,p\,h'$, the section will be an ellipse, $m\,n\,h$. 4th. When the plane is parallel to one of the sides of the cone, as $r'\,h'$, the resulting section is a parabola $r\,s\,h\,t\,u$, which may be considered as an ellipse, infinitely elongated. 5th. When the section plane is such as to pass through the sides of another cone formed by producing the sides of the first, the resulting curve in each cone is a hyperbola.

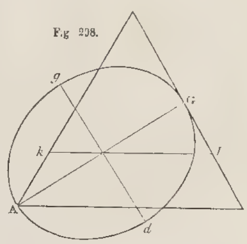
Several methods of drawing the curves of the conic sections have already been given in the section on practical geometry. Here their projections, as resulting from the sections of the solid by planes, are to be considered. If the mode of finding the projections of a point on the surface of a given cone be understood, the projections of the curves of the conic sections will offer no difficulty. Let the problem be:—First, to find the projections of the section made by the plane $m'\,h'$. Take at pleasure upon the plane several points, as p', &c. Let fall from these points perpendiculars to the horizontal plane, and on these will be found the horizontal projection of the points: thus, in regard to the point p'—Draw through p' a line parallel to A B: this line will be the vertical projection of a horizontal plane cutting the cone, and its horizontal projection will be a circle, with $s'\,n'$ for its radius. With this radius, therefore, and from the centre c, describe a circle cutting, twice, the perpendicular let fall from p, which will be the projections sought of certain points in the circumference of the ellipse. In the same manner, any other points may be obtained in its circumference. The operation may often be abridged by taking the point p in the middle of the line $m'\,h'$; for then $m\,h$ will be the major, and $n\,c$ the minor axis of the ellipse.

To obtain the projections of the parabola, more points are required, such as r', 2, s', 3, h'.

The projections of the section plane which produces the hyperbola, are straight lines, $q\,h'$, $z\,h$.

The development of these curves, that is, their projections on planes parallel to the section planes which produce them, may be here illustrated.

Fig. 298.



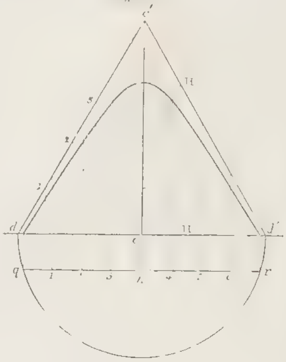
First, The *ellipse*. The development of this curve is found by making its major axis equal to A G, and its minor axis $g\,d$, equal to $k\,l$, as has been explained.

Second, The *parabola* (Fig. 297 A). Draw the line $u\,u'$ parallel to E F, and the line $n\,h'''$ perpendicular to it and bisecting it. From the horizontal projection take the length $g\,u$, and carry it from n to u and u'. Take also $g\,x$, and carry it from n to 2; and in the same way transfer the lengths $g\,c$, $g\,v$, &c., to $n\,t$, n 3, &c., and through each of these points draw perpendiculars to E F, and set up on them from the line $u\,u'$ the heights of the corresponding points 2 s' 3, from the line m' B of the vertical projection: the points through which to trace the curve will thus be obtained.

Third, the *hyperbola*. Draw the line $c\,c'$ (Fig. 299) per-

pendicular to $d\,d'$, and make $d\,d'$ equal to the base, and $c\,c'$ equal to the height of the cone. From c as a centre, with the radius $c\,d$, describe a semicircle equal to half the base of the cone, and draw $r\,q$, the section plane, at the distance from the centre of E q, or $c\,h$, in Fig. 297. Divide the line $r\,q$ into any number of equal parts in 1, 2, 3, h, &c., and through them draw lines perpendicular to $d\,d$. From c as a centre, with the radii c 1, c 2, &c., describe arcs cutting $d\,d'$; and from the points of intersection draw perpendiculars cutting the sides of the cone in 1, 2, 3; and these heights transferred to the corresponding perpendiculars drawn directly from the points 1, 2, 3, &c., in $r\,q$, will give points in the curve.

Fig. 299.



Understanding clearly the principles of construction here developed, no difficulty will be experienced in apprehending the methods of construction employed in developing these curves under the head of Sections of Solids.

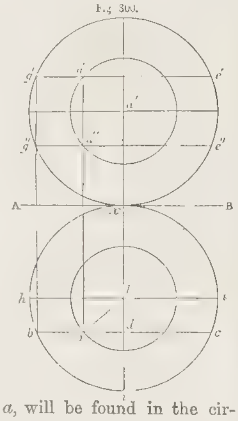
Of the Section of the Sphere by a Plane.

A point in one of the projections of the sphere being given, to find it in the other projection.

Let a be the given point in the horizontal projection of the sphere $h\,x\,i\,v$.

Any point whatsoever on the surface of a sphere belongs to a circle of that sphere: therefore, if a (Fig. 300) be the point, and a plane $b\,c$ is made to pass through that point parallel to A B, the section of the sphere by this plane will be a circle, whose diameter will be $b\,c$, and the radius, consequently, $d\,b$ or $d\,c$; and the point a will necessarily be in the circumference of this circle. Since the centre d of this circle is situated on the horizontal axis of the sphere, d will also be the centre of the sphere; and as this axis is perpendicular to the vertical plane, its vertical projection will be the point d'. It is evident that the vertical projection of the given point a, will be found in the circumference of the circle described from d' with the radius, and at that point of it where it is intersected by the line drawn through a, perpendicular to A B. Its vertical projection will therefore be either a' or a'', according as the point a is on the superior or inferior semi-surface of the sphere.

Fig. 300.

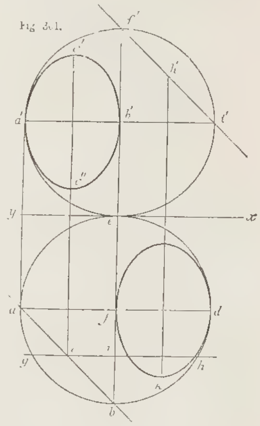


The projection of the point may also be found by an inverse operation, thus:—Conceive the sphere cut by a plane parallel to the horizontal plane of projection passing through the given point a. The resulting section will be the horizontal circle described from k, with the radius $k\,a$; and the vertical projection of this section will be the straight line $g'\,e''$, or $g''\,e''$; and the intersections of these lines with the perpendicular drawn through a, will be the projection of a, as before.

The traces of a plane cutting a sphere being given, to find the projections of the action.

Let $a\,b$ (Fig. 301) be the horizontal trace of the section plane. On the line of section take any number of points, as a, c, b, and through each of them draw a line perpendicular to $y\,x$. As the point a is situated on the circumference of the great circle of the sphere, its vertical projection will be on the vertical projection of the circle at a'. The point b being the extremity of the axis of the sphere, will have its vertical projection b' in the projection of the great circle $e\,f$. The projection of c, or of any other point in the line $a\,b$, is found in either of the ways detailed in the preceding problem. Practically, in this case, it is found thus:—Through c draw $g\,c\,h$ parallel to $y\,x$, and also $c\,c'$ perpendicular to $y\,x$; then with the radius $i\,g$, or $i\,h$, and from the centre b' on the vertical projection, describe arcs of a circle, cutting the perpendicular $c\,c''\,c'$ in c' and c''. Then c being in this case the middle of the line of section $a\,b$, the vertical projection will be an ellipse, whose major axis will be $c'\,c''$, and minor axis $a'\,b'$.

Fig. 301.

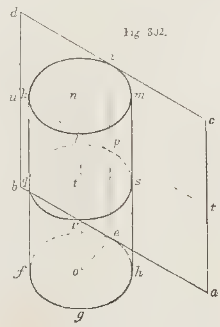


TANGENT PLANES TO CURVED SURFACES.

Tangent Plane to a Cylinder.

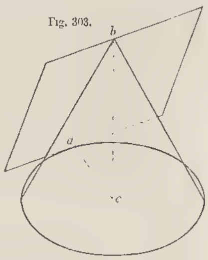
Let the lines $a\,b$, $c\,d$ (Fig. 302), be tangents to the generating circles $e\,f\,g\,h$, $i\,k\,l\,m$, of the cylinder $g\,l$. As the circles are parallel, the tangents will also be parallel and perpendicular to the radii $n\,i$, $o\,e$. If through these two tangents a plane, $a\,d$, pass, it will be perpendicular to the rectangle $i\,o$; and on the generating line $e\,i$ will, consequently, be found the tangent points of all circles which can be conceived to be drawn between the base and summit of the cylinder. And as, in the formation of the cylinder by the generating circle, the radius $n\,i$ has been supposed

Fig. 302.



to pass through all the points of the line *e i*, the plane *a d* will contain all the tangents of all the circles supposable in the cylinder, such, for example, as the circle *p q r s*, the tangent of which is *t u*: the plane *a d* is therefore a tangent to the cylinder in the right line *e i*. The axis of the cylinder, *o n*, is named the directrix; because, in conceiving the cylinder formed by the motion of the generating circle, the centre of the circle will move in the direction *o n*. In considering the circle as formed by the rotation of the rectangle *o i* round its side *o n*, it is seen that the generatrix *e i* is necessarily parallel to the directrix *o n*, and that *i* is the point of contact of the generatrix *i e* and the generating circle *i k l m*, and through this the tangent passes. Consequently, if through any tangent point on the circumference of the generating circle of a cylinder, a line is drawn parallel to the directrix, it will be the line in which a tangent plane will touch the cylinder.

Fig. 303.



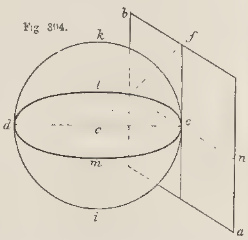
Tangent Plane to a Cone.

The cone differs from the cylinder in that the generatrix *a b* (Fig. 303) is not parallel to the directrix *c b*, and that it passes always through the summit *b*.

Tangent Plane to a Sphere.

Let *a b* (Fig. 304) be a plane perpendicular to the extremity of the radius *c e*. If through any point *f* in the plane there be drawn the right lines *f c*, *f e*, there will be formed the right-angled triangle *c e f*. As the side *c e* of the triangle *c e f* is equal to the radius of the sphere, the point *f* will be a point in space without the sphere; and it will obviously be the same in regard to any point taken in *a b*, except alone the point *e*. Therefore, every plane perpendicular to a radius of a sphere, and at its extremity, will be a tangent to the sphere.

Fig. 304.



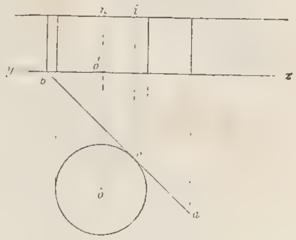
It may also be thus demonstrated:—If the line *e f* (Fig. 304) is perpendicular to the radius of the circle *d i e k*, it will be a tangent to that circle; and if the line *e n* is perpendicular also to the radius of the circle *d m e l*, it will be a tangent to that circle (the radius *c e* being common to both circles). Now, two straight lines which intersect each other are in the same plane, since the three points *n e f* are not in the same straight line; consequently, if a plane pass through these lines it will be perpendicular to *e c*, and tangential to the two circles, which are both generating circles of the same sphere. Hence, if through the point of contact of two generating circles of a sphere two tangents be drawn, these tangents will determine the tangent plane of the sphere at that point.

Having thus illustrated, generally, the subject of tangent planes to curved surfaces, it will now be proper to show the practical application of the principles.

Through a given point in the circumference of the base of a right cylinder, to draw a tangent plane.

Let *e* (Fig. 305) be the given point on the horizontal projection: draw the radius *o e*, and through its extremity *e* draw perpendicular to it the line *a b*, which is a tangent to the circle, and is the trace of the tangent plane sought. Through *e* draw the line *e i*, perpendicular to *y z*, and it gives on the vertical projection the tangent line *e′ i* of the plane, which is parallel to the directrix *o n*, as has been seen.

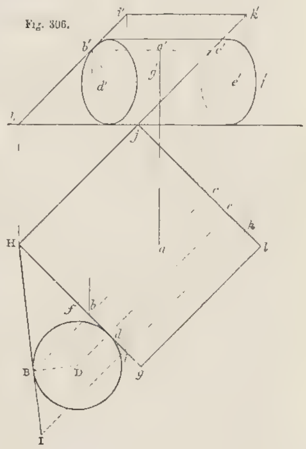
Fig. 305.



Through a given point on the surface of a right cylinder to draw a tangent plane.

Let *a* (Fig. 306) be the horizontal projection of the point: through *a* draw *b c* parallel to the axis *d e*, and *b c* will be the horizontal projection of the tangent line of the plane. Find, then, the vertical projection of *a* by the rules already given. Let this be *a′*: through *a′* draw *b′ c′* parallel to the axis *d′ e′*, and this will be the vertical projection of the tangent line. Now, to find the tangent plane, draw, in the horizontal projection, the circle of the base of the cylinder *f g*, produce *c b* to B, the tangent point of the plane with the base, draw the radius D B, and the tangent to it I H, cutting *g f* produced in H. Then I H will be the profile of the plane, and *i* H its horizontal projection; and I H *i* will be the angle which the plane makes with the horizontal plane. From I draw I *k* parallel to H *j*, and the horizontal projection of the tangent plane is obtained in H *j k i*, and from this the vertical projection will be easily constructed.

Fig. 306.

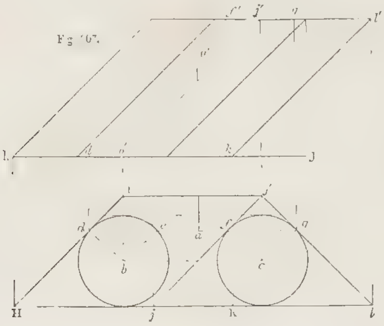


To find the tangent plane when the cylinder is oblique.

Let *a* (Fig. 307) be the given point on the surface of an oblique cylinder with a circular base: on its horizontal projection draw an indefinite line parallel to the axis *b c*, cutting the two bases of the cylinder, each in two points *d e*, *f g*, which will be the extremities of two tangent lines *d f*, *e g*, one on the upper, and the other on the lower part of the surface of the cylinder. To proceed first with the line of the upper surface, *d f*:—The vertical projection of *d* will be *d′*, and that of *f* will be *f′*. Since these two points are the extremities of the

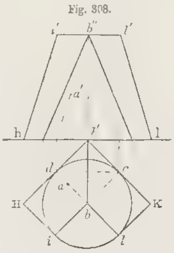
tangent line, draw the line $d' f'$, which will be the tangent. Through a draw an indefinite line perpendicular

Fig. 307.



to $h j$, cutting $d' f'$ in a', the vertical projection of a. To obtain the traces of the tangent plane, through d draw indefinitely the tangent H d b, which will be the horizontal projection sought; and $b' j'$ in the plane of the axis b c, will be the vertical projection of the same plane. If it is desired to limit this plane, take, on the horizontal projection b d produced, any point desired, such as H, whose vertical projection will be h. Through this point draw h i' parallel to the vertical projection of the cylinder, and this line will be one of the limits sought. In the same way will be obtained the boundaries b j, b' j', i j, i' j', &c. To obtain now the tangent plane to the under part of the surface:—Through e draw d g, and the tangent b e k, and operate as directed for the first plane. In Fig. 308 the same problem, but with the cone in place of the cylinder, is shown; and as nearly the same letters are used, no other description is required.

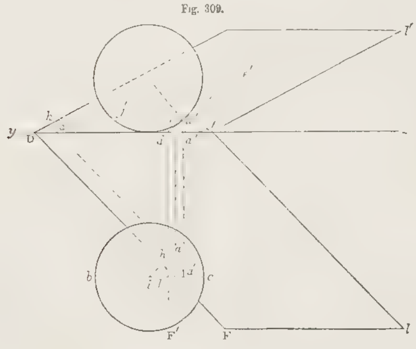
Fig. 308.



Through a given point on the surface of a sphere, to draw a tangent plane to that surface.

Let a (Fig. 309) be the given point in the horizontal

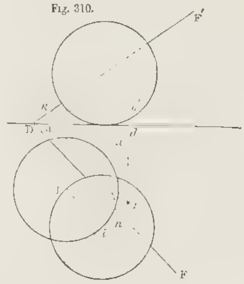
Fig. 309.



projection. As in the case of the cylinder, it is to be considered whether the point is on the upper or lower part of the surface. Let it be on the lower surface:—Conceive the point turned round horizontally until it has arrived at a', on the diameter b c, which may be considered as the horizontal projection of a great circle of the sphere, parallel to the vertical plane; consequently, the vertical projection of a will be a''. If through this point the tangent d e' be drawn, this line will be the vertical projection of a tangent plane to the sphere, perpendicular to the vertical plane; consequently, the line d F', perpendicular to y z, will be the horizontal projection of the same plane, which will be inclined to the horizontal plane in the angle e' d z: through a'' draw a horizontal line a'' g', cutting the vertical line drawn upon a in the point a', which will be the vertical projection of a, or the tangent point. Conceive now the point a turned back to its first position, and that the plane e' d F, which contains a', had turned with it, it is clear that when a' is in a, the point h' will be in h, and will not have left the horizontal plane; consequently, the trace d F, which was perpendicular to the radius i h', will be in D F, and will continue perpendicular to i h. There remains only to find the vertical trace of the plane. Draw the line a a''' parallel to D F: it will be perpendicular to the radius i a, as a' a'' was to i a' before being turned. This line a a''' being horizontal at the height of the point of the tangent, and situated in the tangent plane, its extremity will necessarily be in the vertical projection sought. Raise on a''', therefore, the vertical line, cutting a g' in k, the point sought. Now, D being also one of the points of the projection, the line D k produced will be the vertical projection sought. If the plane be limited, its vertical and horizontal projections will be the rhombuses D l, D l'.

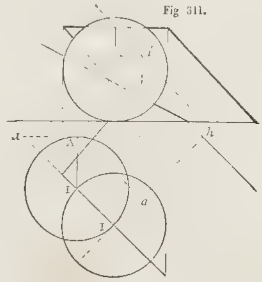
The same end can be arrived at in a way more direct, simple, and expeditious, but which could not be so easily understood without a knowledge of the previous mode.

Fig. 310.



Let a (Fig. 310) be the point given. Through it, and the centre i, draw the diameter a i, which consider to be the projection of a section plane. If this is now laid down in the horizontal plane, there will be obtained a great circle of the sphere, as the vertical projection of the section through the diameter. Through a draw a line perpendicular to a i, cutting the circle in A: through this point draw the tangent x A h, which will be the profile of the tangent plane, meeting the horizontal plane in h. Through h draw D h F perpendicular to a i, and D h F will be the horizontal projection of the tangent plane. Through a draw a vertical line, and upon it set off the height a A from d to a'. The remainder of the operation is the same as in the former example

Fig. 311.



The next figure (Fig. 311) shows the process when the plane is a tangent to the upper surface.

INTERSECTIONS OF CURVED SURFACES.

When two solids having curved surfaces penetrate or intersect each other, the intersections of their surfaces form curved lines of various kinds. Some of these, as the circle, the ellipse, &c., can be contained in a plane; but the others cannot, and are named curves of double curvature. The solution of the following problems depends chiefly on the knowledge of how to obtain, in the most advantageous manner, the projections of a point on a curved surface; and is in fact the application of the principles elucidated in the preceding problems. The manner of constructing the intersections of these curved surfaces which is the most simple and most general in its application, consists in conceiving the solids to which they belong as cut by planes, according to certain conditions, more or less dependent on the nature of the surfaces. These section planes may be drawn parallel to one of the planes of projection; and as all the points of intersection of the surfaces are found in the section planes, or on one of their projections, it is always easy to construct the curves by transferring these points to the other projection of the planes.

The projection of two cylinders which intersect at right angles being given, to find the projections of their intersections.

Conceive, in the horizontal projection (Fig. 312), a series

Fig. 312.

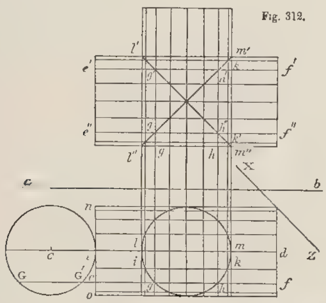
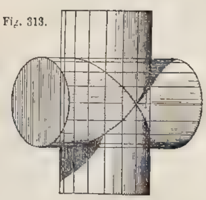


Fig. 313.



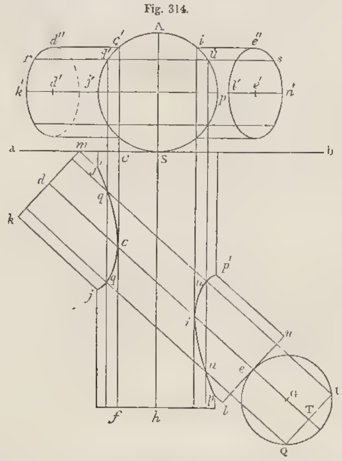
of vertical planes cutting the cylinders parallel to their axes. The vertical projections of all the sections will be so many right-angled parallelograms, similar to $e' f'$, or $e'' f''$, which is the result of the section of the cylinder by the vertical plane $e f$, for this plane cuts the cylinder from surface to surface. The circumference of the second cylinder, whose axis is vertical, is also cut by the same plane, which meets its upper surface at the two points g, h, and its under surface at two corresponding points. The vertical projections of these points are on the lines perpendicular to a b, raised on each of them, so that upon the lines $e' f'$, $e'' f''$, will be situated the intersections of these lines at the points $g' h'$, $g'' h''$, and the same with the other points i, k, l, m. It is not necessary to draw a plan to find these projections. All that is actually required, is to draw the circle representing one of the bases, as n o, of the cylinder laid flat on the horizontal plane. Then to produce g h till it cuts the circle at the superior and inferior points G′ G, and to take the heights e G′, e G, and carry them, upon a b, from g to g', g'', and from h to h', h''.

Fig. 313 is the projection made on the line X Z.

To construct the projections of two cylinders whose axes intersect each other obliquely.

Let A (Fig. 314) be the vertical projection of the two

Fig. 314.



cylinders, and h S d e the horizontal projection of their axes.

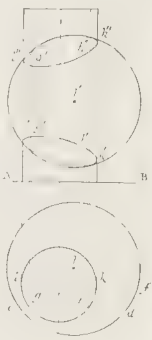
Conceive, in the vertical projections, the cylinders cut by any number of horizontal planes: the horizontal projections of these planes will be rectangles, as in the preceding example, and their sides will be parallel to the axes of the cylinders. The points of intersection of these lines will be the points sought. Without any previous operation, six of those points of intersection can be obtained. For example, the point c' is situated on d'' e'', the highest point of the cylinder; consequently, the horizontal projection of c' is on d e, the horizontal projection of d'' e'', and it is also on the perpendicular let fall from c', that is to say, on the line c f parallel to the axis of the cylinder S h. The point sought will, therefore, be the intersection of those lines at c. In the same way i is obtained. The point j is on the line k l, which is in the horizontal plane passing through the axis d' e': the horizontal projections of $k' l'$ are k l, and its opposite m n; therefore, in letting fall perpendiculars from j' p', the intersections of these with k l, m n, give the points j j', p p'. Thus six points are obtained. Take at pleasure an intermediate point q', through this point draw a line r s parallel to a b, which will be the vertical projection of a horizontal plane cutting the cylinder in q. The horizontal projection of this section will be, as in the preceding examples, a rectangle which is obtained by taking, in the vertical projection, the height of the section plane above the axis $d' e'$, and carrying it on the base in the horizontal projection from G to T. Through T is then to be drawn

the line Q U perpendicular to G T; and through Q and U lines parallel to the axis; and the points in which these lines are intersected by the perpendiculars let fall from q' u' are the intermediate points required. Any number of intermediate points may be thus obtained; and the curve being drawn through them, the operation is completed.

To find the intersections of a sphere and a cylinder.

Draw, in the horizontal projection, and parallel to A B (Fig. 315), as many vertical section planes as are considered necessary, as $e\,f$, $c\,d$. These planes cut at the same time both the sphere and the cylinder, and the result of each section will be a circle in the case of the sphere, and a rectangle in the case of the cylinder. Through each of the points of intersection g, h, i, k, draw indefinite lines perpendicular to A B. Take the radius of the circles of the sphere proper to each of these sections, and with them cut the correspondent perpendiculars in $g\,g'$, $h\,h'$, $i\,i'$, &c., and draw through these points the curves of intersection. This operation should be so obvious from the preceding problems, that it is not necessary to enter more particularly into the description.

Fig 315.

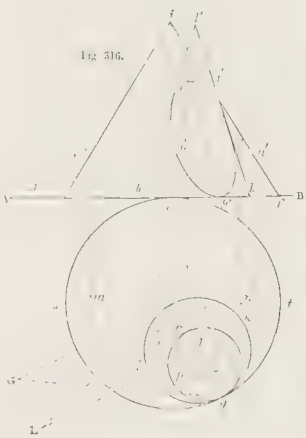


To construct the intersection of two right cones with circular bases.

The solution of this problem is founded on the knowledge of the means of obtaining on one of the projections of a cone a point given on the other.

Let A B (Fig. 316) be the common section of the two planes of projection, the circles $g\,d\,e\,f$, $g\,h\,i\,k$, the horizontal projections of the given cones, and the triangles $d'\,i'\,f'$, $h'\,l'\,k'$, their vertical projections. Suppose these cones cut by a series of horizontal planes: each section will consist of two circles, which cutting each other, and the points of their intersection, will be points of intersection of the conical surfaces. For example, the section made by a plane $m'\,n'$ will have for its horizontal projections two circles of different diameters, the radius of the one being $i\,m$, and of the other $l\,o$. The intersecting points of these are p and q, and these points are common to the two circumferences; and their vertical projection on the plane $m'\,n'$, will be in $p'\,q'$. Thus, as many points may be found as is necessary to complete the curve. But there are certain points of intersection which cannot be rigorously established by this method without a great deal of manipulation, and it is therefore advisable to point out another method of procedure for such cases.

Fig. 316.



The point r in the figure is one of those; for it will be seen that at that point the two circles must be tangents to each other, and it would be difficult to fix the place of the section plane $s'\,t'$ so exactly by trial, that it would just pass through that point.

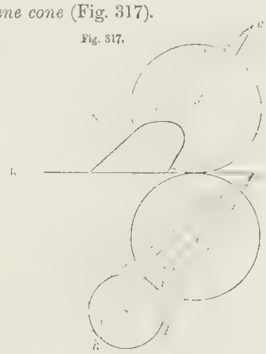
It will be seen that the point r must be situated in the horizontal projection of the line $g\,i$, which passes through the summits of both cones. This line $g\,i$ is the projection of a vertical plane, which contains—1st, the side of the large cone, passing through the summit G, and terminating at the base in i; and, 2d, the side of the smaller cone passing through the summit L, and also terminating at the base in i. These two lines must intersect each other at the surface of the cones, and the point r will be the point of intersection. Hence, to find r:—Through i in the horizontal projection raise on $g\,i$ a perpendicular equal to the height of the cone $g\,g''$, and draw G g, which will be the side of that cone. Through l raise a perpendicular, and make it equal to the height of the second cone, and draw its side L i; and from the point of intersection let fall a perpendicular on $g\,i$, meeting it in r; and through r draw an indefinite line perpendicular to A B, and set up on it from the horizontal projection the height of the point of intersection r.

There is still another method by which the operation is abridged. Find the two points i and r, and consider $i\,r$ as a diameter: from u as a centre, with the radius $u\,r$, describe a circle, the circumference of which will be the horizontal projection of the intersection of the two cones. It now remains to find the vertical projection of this circle, which can be done by the methods pointed out in preceding problems.

To construct the intersections of a sphere penetrated by an oblique scalene cone (Fig. 317).

This problem is not very different from the preceding one; but yet the method of solution given for that could not be advantageously applied to this, and would be quite inapplicable if the base of the cone were irregular, a circumstance which proves the necessity of knowing several methods of solution for each case.

Fig. 317.

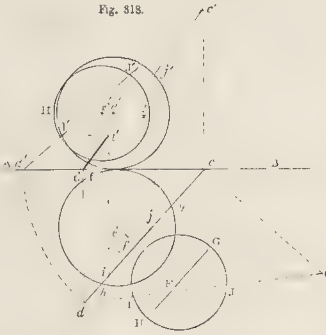


Conceive the cone in this case cut by a number of vertical planes, all passing through its summit and its base: the sections made by them will all be triangles, easy to determine; and the sections of the sphere by the same planes will be so many circles, quite as easily constructed. Whence it results, that the operation is resolved into finding the intersections of a straight line and a circle. Not to overcrowd the figure, the operation is shown only in part.

Let $c\,d$, $c'\,d'$ (Fig. 318), be the projections of the line given: this line will be analogous to the side $c\,d$ of the cone in Fig. 317. Conceive $c\,d$ to be the horizontal projection of a vertical plane cutting the sphere. The section resulting from this plane will be a circle contained in the plane, and of which the radius will be $f\,h$, or $f\,g$. If this section be turned down on the horizontal plane, there will result the right-angled triangle $d\,c$ C, whose hypothenuse d C will cut the circle of the spherical section in I and in J. From these two points let perpendiculars fall on $d\,c$, meeting it in $i\,j$, which will be the horizontal projections of the points of the entry and exit of the cone into the sphere, and the vertical projections of the same will be $i'\,j'$. In repeating this operation for every one of the lines in Fig. 318, points will be obtained through which to draw the curves of intersection; but this may be abridged, as now to be shown.

Suppose the plane containing the triangle and the circle which was turned down on the horizontal plane, to be raised up by turning on the point c, in describing the arc $d\,d'$; then this plane will apply to the vertical plane without any alteration; consequently, the points I′ and J′ will be elevated above A B to the same extent as are the projections $i\,j$, and so will likewise be the centres F′ e' of the two circles.

Fig. 318.



From c, as a centre, with the radius $c\,d$, describe the arc $d\,d'$; and from the same centre, with the radius $c\,f$, describe the arc f f. From the last point raise a perpendicular, on which set off the height of the radius of the sphere from f to F′; and from F′, as a centre, with the radius F G or F H, describe a circle, or rather an arc, cutting $d'\,c'$ in I′ J′: from each of these points draw lines parallel to A B, which will cut d c' in i and j, the points of intersection sought.

To construct the intersections of two right cones with circular bases.

To commence by a very simple example (Fig. 319). Conceive, in the horizontal projection, a vertical plane cutting both cones through their axes: the sections will be two triangles, having the diameters of the bases of the cones as their bases, and the height of the cones as their height. And as in the example the cones are equal, the triangles will also be equal, as the triangles $c\,e'\,f$, $g\,f'\,d$, in the vertical projection. Conceive now this same vertical plane passing through the different points of the base, but still passing through the summits of the cones: the sections which result will still be triangles (as has already been demonstrated), whose bases diminish in proportion as the plane recedes from the centres of the bases, until at length the plane becomes a tangent to both cones, and the result is a tangent line whose projections are h, g, h, f, $g\,e'$, $f\,f'$. It will be observed that the circumferences of the bases cut each other at m and i, which are the first points of their intersections, and whose vertical projections are the point m merely. If the projections of the other points of intersection on the lines of the section planes are found (an

Fig. 319.

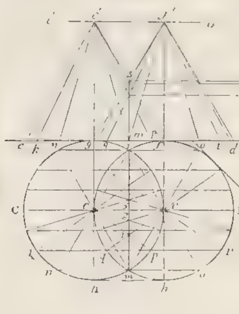
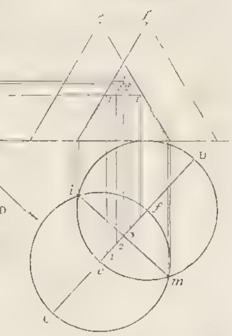


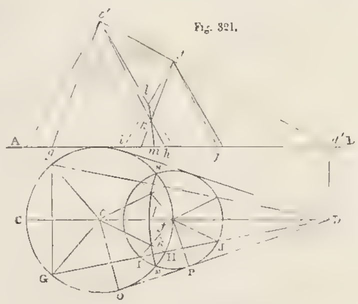
Fig. 320



operation presenting no difficulty, and easily understood by the inspection of the figure), it will be seen that the horizontal triangles $n\,c\,m$, $m\,c\,o$, $k\,c\,p$, $q\,c\,r$, &c., have for their vertical projections the triangles $n\,e'\,m$, $m\,f'\,o$, $k\,e'\,p$, &c., and that the intersections of the cone are in a plane perpendicular to both planes of projection, and its projections are the right lines $i\,m$, m 3. From the known properties of the conic sections, the curve produced by this plane will be a hyperbola. Fig. 320 is the projection of the cones on the line o X.

The next example (Fig. 321) differs from the first in the inequality of the size of the cones. Suppose an indefinite line C D, to be the horizontal projection of the vertical section plane, cutting the two cones through their axes $e\,f$. Conceive in this plane an indefinite line $e\,f$ D, passing through the summits of the cones, the vertical projection of this line will be $e'\,f'\,d'$: from d, let fall on C D a perpendicular meeting it in D: this will be the point in which the line passing through the summits of the cones will meet the horizontal plane; and it is through this point, and through the summits e and f, that the section planes should be made to pass, as in the preceding example. The horizontal projections of these planes are O D, G D, C D, &c.: O D is then the projection of a tangent plane to the two conical surfaces O e, P f; and the plane passing through the projection G D, and the line e D, cuts the greater cone, and forms by the section the triangles G e H in the horizontal, and $g\,e'\,h$ in the vertical projection; and it cuts the lesser cone, and forms the triangles I f J, $i\,f\,j$. In the horizontal projection it is seen that the sides H e, I f of the triangle intersect in k, which is therefore the horizontal projection of one of the points

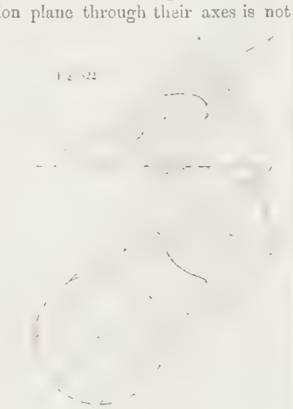
Fig. 321.



of intersection; and its vertical projection is k. In the same manner, the other points required may be found. It is seen at once that M N, $l\ l'$, are points in the intersection, and the curve formed by it is traced through the points M $k\ l$ N in the horizontal, and $m\ k\ l$ in the vertical projection.

The next example (Fig. 322) is in some respects analogous to the first, the two cones being of the same height; but the section plane through their axes is not parallel to the plane of projection, and the right cone is penetrated by a scalene cone. There is, however, no difference in the operation, which will be understood by inspection.

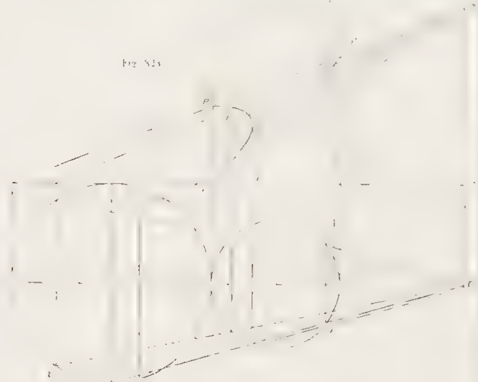
Fig. 322.



Construction of the intersections formed by the penetration of a cylinder by a scalene cone.

Conceive a line $c\ c\ c'$ (Fig. 323) parallel to the generatrix of the cylinder, passing through the summit of the cone; then all the vertical planes which, passing through this line and the base of the cone, cut the latter and the cylinder, follow lines which must be in these planes; for the cone will be cut in triangles, and the cylinder in rectangles; and the intersections of these lines from the cone and cylinder will give points in the line sought. Thus, as in this case, the generatrix of the cylinder is vertical, the line $c'\ c$ C drawn parallel to it through the summit of the cone will also be vertical, and its vertical projection will be $c\ c'$, and its horizontal projection C. Through this point C, therefore, and through the base of the cone, must be made to pass the vertical planes required. For instance, the vertical plane D C cuts the cone through its axis, and the section is the triangle $d\ c'\ e$; and it cuts the cylinder, and the section is the rectangle $e f'$. These two figures intersect each other in $e\ e'$, $g\ g'$; and these intersections give $e\ g$, two of the points sought. The plane H C gives also a triangle and rectangle, intersecting in $h\ h$.

Fig. 323.



The plane M C, which is a tangent to the cone, gives the line $m\ c'$ on the surface of the cone in the vertical projection, and the rectangle $n\ p$ in the cylinder, and the points of intersection are n' and o. The problem thus presents no difficulty.

Example 2, Fig. 324.—Conceive both the cone and cylinder cut by a vertical plane, of which C d is the horizontal trace. Let this section be turned down on the horizontal plane on C d as a hinge, and the triangle C D E is obtained as the section of the cone, and the circle f G H as the section of the cylinder. In this section the line

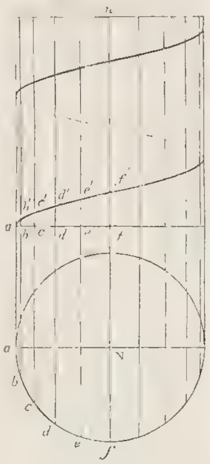
Fig. 324.

C D is tangent to the circle in G; and a plane parallel to the axis or generatrix of the cylinder, passing through the summit D or d of the cone, and through the point C, would be a tangent to the surfaces of both the cone and the cylinder. The point G, therefore, which is common to both those surfaces, and whose projections are $g\ h$, is one of the points of intersection. The line E D, which is the lower side of the cone, enters the circle of the cylinder at I, and leaves it at H. These two points are also, therefore, points in the intersection, and their projections are $i\ h$, $i'\ h'$. It is now necessary to find some other point, and to obtain it, proceed as follows:—Through J, taken at pleasure on the line C d, draw parallel to the generatrix of the cylinder the line K L, which will be the projection of a plane passing through the summit and base of the cone: the triangle K d L will be the horizontal projection of the section formed by that plane. Since the plane of this triangle is parallel to the axis of the cylinder, the sides K d, L d will enter the cylinder at the same moment—each by its own point of intersection; and these points of intersection—the points at which they enter and leave the cylinder—will be on generatrices of the cylinder $o\ p$, $q\ r$: it is necessary, therefore, to find those generatrices. Through J, a point taken in the middle of the base of the triangle, draw J D, which will enter the circle at M, and leave it at N: through these points draw the generatrices $o\ p$, $q\ r$, cutting the sides of the triangle in $m\ m$, $n'\ n'$, which are the points sought.

OF HELICES.

Let *a b c d*, &c. (Fig. 325), be any curve whatever, traced on a horizontal plane. (In this example it is a circle.) Take on this curve a series of points *a b c d*, &c., and through each of them draw a vertical line. Then conceive a curve cutting all these verticals in the points *a′ b′ c′ d′*, in such a manner that the height of the point above the horizontal plane may be in constant relation to the arcs *a b*, *b c*, *c d*; for example, that *a* may be the zero of height, that *b b′* may be 1, *c c′* 2, *d d′* 3, &c.; then this curve is named a helix. To construct this curve, carry on the vertical projection on each vertical line such a height as has been determined, as 1 on *b*, 2 on *c*, 3 on *d*; and through these points will pass the curve sought. It is easy to see that the curve so traced is independent of the cylinder on which it has been supposed to be traced; and that if it be isolated, its horizontal projection will be a circle. The helix is named after the curve which is its horizontal projection: thus the helix in the example, is a helix with a circular base. The vertical line *f n* is the axis of the helix, and the height *b b′*, comprised between two consecutive intersections of the curve with a vertical, is the pitch of the helix.

Fig. 325.



The points *a b c d*, &c., being in the circumference of a circle, are, of course, situate at the same distance from its centre. Conceive now that each of these points approaches nearer to the centre in a constant ratio, such, for example, as 1, 2, 3, 4, 5 (Fig. 326). The curve then drawn through these points, when supposed to be in the same plane, is called a spiral. If these points, in addition to approaching the centre in a constant ratio, are supposed also to rise above each other by a constant increase of height, a curve will be obtained, which is also called a spiral. This spiral may be conceived to be traced on the surface of a cone (Fig. 326). It may also be traced on the surface of a sphere (Fig. 327). These figures do not require detailed description.

Fig. 326.

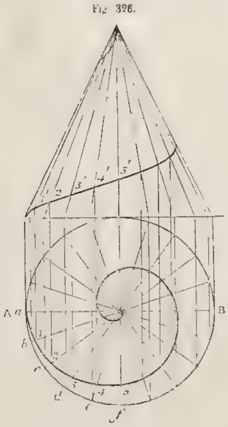
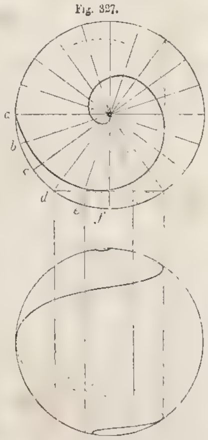


Fig. 327.



MANNER OF TAKING DIMENSIONS.

In taking the dimensions of any triangular figure, make a sketch of it as in Fig. 328, No. 1, and on each line of the sketch mark the dimensions of the side of the figure it represents. Then, in describing the figure, either to its full dimensions, or to any proportionate scale, draw any straight line as A B, No. 2, and make it equal to the dimension marked on the corresponding line A B of the sketch No. 1. From the centre A, and with the radius A C, describe an arc at C; then from the centre B, with the radius B C, describe an arc intersecting the former: join A C, B C, and the triangle A C B is the figure required.

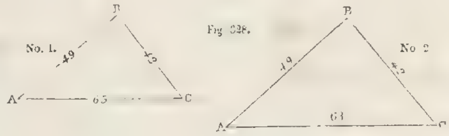


Fig. 328.

The dimensions of any figure are taken on the principle above illustrated. If the figure is not triangular, it is divided into triangles, in the manner shown by Fig. 329, Nos. 1 and 2.

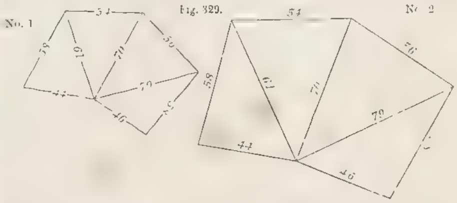


Fig. 329.

In Fig. 330, Nos. 1 and 2, the manner of taking dimensions, when one or more sides of the figure are bounded by curved lines, is illustrated. When, as at A B (No. 1), the side is a circular arc, its centre is obtained as follows:—The extreme points A B, and the point of junction C of the intermediate line E C with A C and B C, give three points in the curve. From A and B, therefore, with any radius, describe arcs above and below the curve; from C, with the same radius, intersect these arcs; through the intersections draw straight lines meeting in D; and D is the centre of the curve, and D A, D B, or D C its radius.

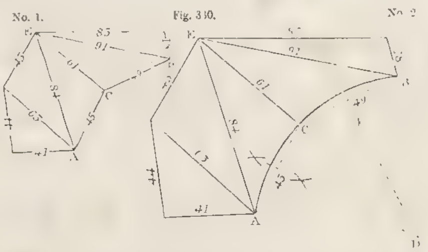


Fig. 330.

SECTIONS OF SOLIDS.

Plate I.

Plate I. *Fig.* 1.—*To draw the sections of a cone made by a line cutting both its sides.*

Let A D B be the vertical projection of the cone, A C B the horizontal projection of half its base, and E F the line of section. From the points E and F, let fall on A B the perpendiculars E G, F H; and on G H describe the semicircle G 4 H, which is the horizontal projection of half of the section. To find the vertical section—Divide the semicircle G 4 H into any number of equal parts, 1 2 3 4, &c.; and through these divisions draw lines 1 5 K, 2 6 *l*, 3 7 *m*, 4 8 *n*, perpendicular to the line A B, and meeting the section line E F in the points *k l m*, &c. Through *k l m*, &c., draw *k t*, *l u*, *m v*, *n w*, perpendicular to E F, and make them respectively equal to the corresponding ordinates, 5 1, 6 2, 7 3, &c., of the semicircle G 4 H, and points will be obtained through which the ellipse E *w* F may be traced. It is obvious that, practically, it is necessary only to find the minor axis of the ellipse, the major axis E F being given.

If through the points E *k l m n*, &c., lines be drawn parallel to A B, &c., meeting the side of the cone, as in *o p q r s*, and from these perpendiculars be let fall on A B, in *x y z a b*, then arcs described from the centre of the base of the cone I, with the radii I G, I 1, I 2, will meet these perpendiculars. This is applied in the two following figures, to finding the projections of other sections of the cone.

Figs. 2 and 3.—*To draw the sections of a cone made by a line parallel to one of its sides.*

Let A D B be the vertical projection of a right cone, and A C B half the plan of its base; and let E F be the line of section. In E F take any number of points, E *a b c d e* F, and through them draw lines E H, *a* 6 1, *b* 7 2, &c., perpendicular to A B. Through *a b c d e*, draw also lines parallel to A B, meeting the side of the cone in *f g h k l*: from these let fall perpendiculars on A B, meeting it in *m n o p q*. From the centre of the base I, with the radii I *m*, I *n*, I *o*, &c., describe arcs cutting the perpendiculars let fall from the section line in the points 1 2 3 4 5; and through the points of intersection trace the line H 1 2 3 4 5 G, which is the horizontal projection of the section. To find the vertical section—On E *a b c d e*, raise perpendiculars to E F, and make them respectively equal to the ordinates in the horizontal projection, as E *r* equal to E H, *a s* equal to 6 1, &c., and the points *r s t u v w* in the curve will be obtained.

Fig. 4, Nos. 1–4.—*To draw the section of a cuneoid made by a line cutting both its sides.*

A cuneoid is a solid ending in a straight line, in which, if any point be taken, a perpendicular from that point may be made to coincide with the surface. The end of the cuneoid may be of any form; but in architecture it is usually semicircular or semi-elliptical, and parallel to the straight line forming the other end.

Let A C B (No. 1) be the vertical projection of the cuneoid, and A 5 B the plan of its base, and A B (No. 4) the length of the arris at C, and let D E be the line of section.

Divide the semicircle of the base into any number of parts 1 2 3 4 5, and through them draw perpendiculars to A B, cutting it in *l m n o p*, and join C *l*, C *m*, C *n*, &c., by lines cutting the section line in 6 7 8 9, &c. From these points draw lines perpendicular to D E, and make them equal to the corresponding ordinates of the semicircle, either by transferring the lengths by the compasses, or by proceeding as shown in the figure.

The section on the line D K is shown in No. 2, in which A B equals D K; and the divisions *e f g h k* in D K, &c., are transferred to the corresponding points on A B; and the ordinates *e l*, *f m*, *g n*, &c., are made equal to the corresponding ordinates *l* 1, *m* 2, *n* 3, of the semicircle of the base. In like manner, the section on the line G H, shown at No. 3, is drawn.

Fig. 5.—*To describe a cylindric section through a line given in position.*

Let A B G F be a section of a right cylinder passing through its axis; and let C D be the line of the required section. On A B describe a semicircle, and in the arc take any number of points, 1 2 3 4 5, from which draw lines perpendicular to A B, cutting it in *o p q r s*, and produced to meet the line of section C D, in the points 6 7 8 9 10, &c. From these points draw the lines 6 *t*, 7 *u*, 8 *v*, 9 *w*, 10 *x*, &c., perpendicular to C D, and make these ordinates respectively equal to the ordinates *o* 1, *p* 2, *q* 3, *r* 4, *s* 5; then through the points C *t u v w*, &c., draw the curve, which will be the section required. The heights of the ordinates may be simply transferred by the compass, or thus:—Produce the line of section C D to E, to meet the diameter A B produced: draw E *n* perpendicular to E D, and E *n* perpendicular to E B. From the points in the arc 1 2 3 4 5, draw lines 1 *h*, 2 *k*, 3 *l*, 4 *m*, 5 *n*, meeting the line E *n*; then with the centre E and radii E *h*, E *k*, E *l*, E *m*, E *n*, describe the arcs *h h*, *k k*, &c., and from the points *h k l m n*, where these arcs meet the line E *n*, draw the lines *n x*, *m a*, *l b*, *k c*, *h d*, cutting the ordinates 6 7 8 9 10, &c., in the points *t u v w x a b c d*, through which draw the curve of the required section.

Fig. 6.—*To describe the cylindric section made by a curved line cutting the cylinder.*

Let A B D E be the section of the cylinder, and C D the line of the section required. On A B describe a semicircle, and divide it into any number of parts as before. From the points of division draw ordinates 1 *h*, 2 *k*, 3 *l*, 4 *m*, &c., and produce them to meet the line of the section in *o p q r s t u v w*. Bend a rule or slip of paper to the line C D, and prick off on it the points C *o p q*, &c.; then draw any straight line F G, and unbending the rule, transfer the points C *o p q*, &c., to F *a b c d*, &c. Draw the ordinates *a* 1, *b* 2, *c* 3, and make them respectively equal to the ordinates *h* 1, *k* 2, *l* 3, &c., and through the points found trace the curve.

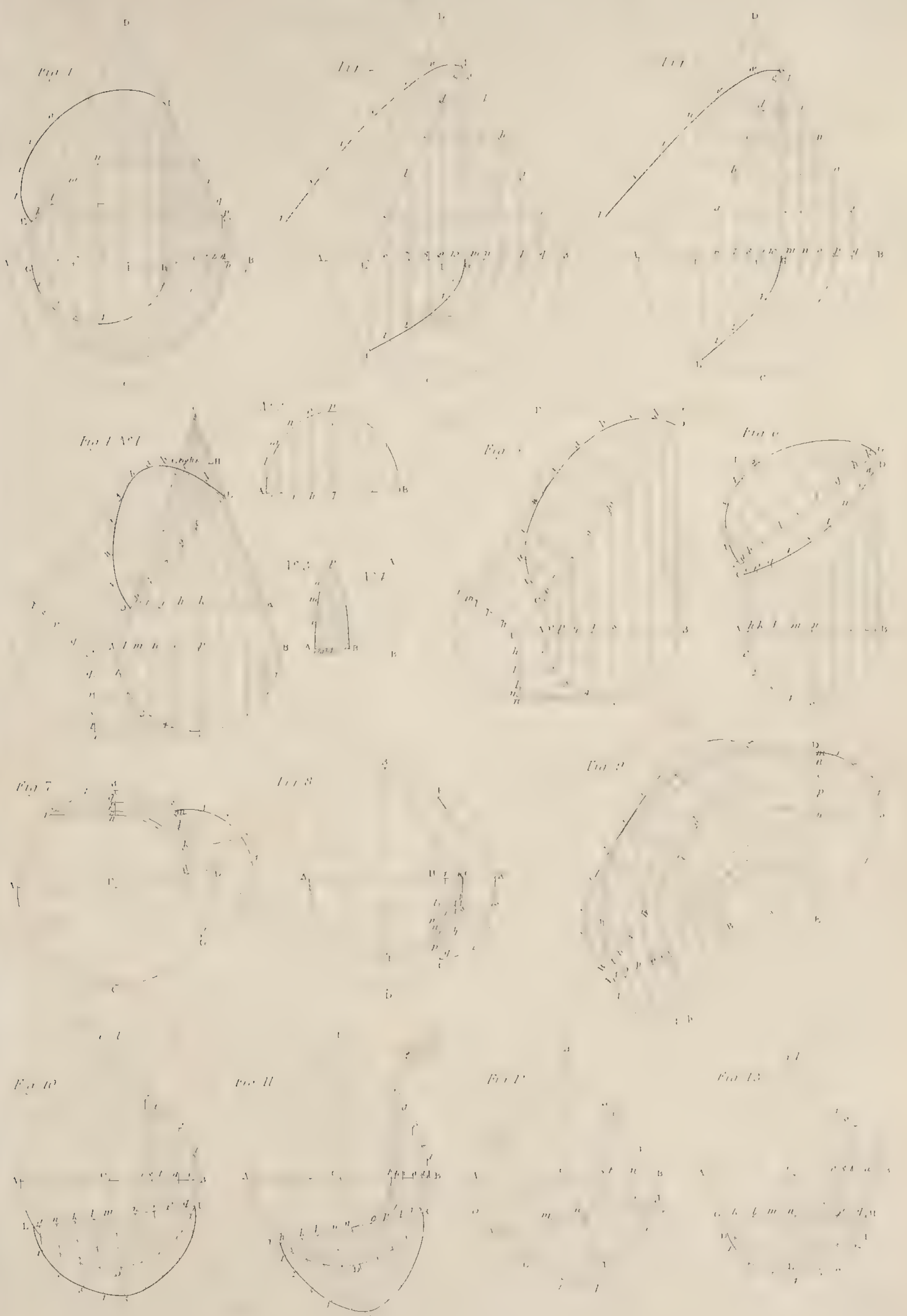
Fig. 7.—*To describe the section of a sphere.*

Let A B D C be the great circle of a sphere, and F G the line of the section required. Then, since, as we have seen, all the sections of a globe or sphere are circles, on F G describe a semicircle F 4 G, which will be the section required.

Or, in F G take any number of points in *m l k* H, and from the centre of the great circle E, describe the arcs H *n*, *k o*, *l p*, *m q*, and draw the ordinates H 4, *k* 3, *l* 2, *m* 1, and *n* 4, *o* 3, *p* 2, *q* 1; then make the ordinates on F G equal to those on B C, and the points so obtained will give the section required.

Fig. 8.—*To describe the section of an ellipsoid, when*

SECTIONS OF SOLIDS.



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a section through the fixed axis, and the position of the line of the required section, are given.

Let A B C D be the section through the fixed axis of the ellipsoid, and F G the position of the line of the required section. Through the centre of the ellipsoid, draw B D parallel to F G; bisect F G in H, and draw A C perpendicular to F G; join B C, and from F draw F K, parallel to B C, and cutting A C produced in K; then will H K be the height of the semi-ellipse forming the section on F G.

Or, the section may be found by the method of ordinates, thus:—As the section of the ellipsoid on the line A C is a circle, from the point of intersection of B D and A C describe a semicircle A E C. Then on H G, the line of section, take any number of points $l\ m\ n\ o\ p$, and from them raise perpendiculars cutting the ellipse in $q\ r\ s$. From $q\ r\ s$ draw lines perpendicular to A C, cutting it in the points 4 5 6; and again, from the intersection of B D and A C as a centre, draw the arcs 4 l, 5 m, 6 n, C o, cutting H G in $l\ m\ n\ o$; then H o, set off on the perpendicular from H to K, is the height of the section; and the heights H n, H m, H l, set off on the perpendiculars from l to 3, n to 2, and p to 1, give the heights of the ordinates.

Fig. 9.—*To find the section of a cylindrical ring perpendicular to the plane passing through the axis of the ring, the line of section being given.*

Let A B E D be the section through the axis of the ring, A B be a straight line passing through the concentric circles to the centre C, and D E be the line of section. On A B describe a semicircle; take in its circumference any points as 1 2 3 4 5, &c., and draw the ordinates 1 f, 2 g, 3 h, 4 k, &c. Through the points $f\ g\ h\ k\ l$, &c., where the ordinates meet the line A B, and from the centre C, draw concentric circles, cutting the section line in $m\ n\ o\ p\ q$, &c. Through these points draw the lines m 1, n 2, o 3, &c., perpendicular to the section line, and transfer to them the heights of the ordinates of the semicircle f 1, g 2, &c.; then through the points 1 2 3 4, draw the curve D 5 E, which is the section required.

Again, let R S be the line of the required section; then from the points $t\ u\ v\ w\ c\ x\ d$, &c., where the concentric circles cut this line, draw the lines t 1, u 2, v 3, &c., perpendicular to R S, and transfer to them the corresponding ordinates of the semicircle; and through the points 1 2 3 4 e 5 f, draw the curve R e f S, which is the section required.

Fig. 10.—*To describe the section of a solid of revolution, the generating curve of which is an ogee.*

Let A D B be half the plan or base of the figure, A a b B the vertical section through its axis, and E F the line of section required. In E F take any number of points, $g\ h\ k\ l\ m\ n\ o\ p\ q\ r$, and through them draw the lines g 1, h 2, k 3, &c., perpendicular to E F. Then from C as a centre, through the points $g\ h\ k$, &c., draw concentric arcs cutting A B in $r\ s\ t\ u\ v$, and through these points draw the ordinates r 5, s 4, t 3, &c., perpendicular to A B. Transfer the heights of the ordinates on A B to the corresponding ordinates on each side of the centre of E F; and through the points 1 2 3 4 5, draw the curve E 5 F, which is the section required.

Fig. 11.—*To find the section of a solid of revolution, the generating curve of which is of a lancet form.*

A D B is the plan of half the base, A E B the vertical section, and F G the line of the required section. The manner of finding the ordinates and transferring the heights, is precisely the same as in the last problem.

Fig. 12.—*To find the section of an octangular pyramid.*

Let A D E F G B be the plan of half the base of the pyramid, A H B a section through its centre, at right angles to any two of its opposite sides, and K L the line of the required section. From the centre C, draw lines to the angles of the pyramid D E F G; then from the points $m\ n\ o$, where these intersect the line of section, draw the lines $m\ p$, $n\ q$, $o\ r$, perpendicular thereto; and through the same points $m\ n\ o$, draw lines parallel to the respective sides of the base, cutting the line A B in $s\ t\ u$. Draw the perpendiculars $s\ x$, $t\ w$, $u\ v$, and transfer the height $s\ x$ to the line $n\ q$, $t\ w$ to $m\ p$, and $u\ v$ to $o\ r$; then join K p, $p\ q$, $q\ r$, r L, and the figure K $p\ q\ r$ L is the required section.

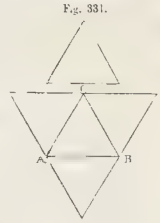
Fig. 13.—*To find the section of an ogee pyramid with a hexangular base.*

Let A D E F B be the plan of the base of the pyramid, A a b B a vertical section through its axis, and G H the line of the required section. Draw the arrises C D, C E, C F. On the line of section G H, at the points of intersection of the arrises with it, and at some intermediate points k, m, o, q, raise indefinite perpendiculars. Through these points $k\ l\ m\ n\ o\ p\ q$ draw lines parallel to the sides of the base, as shown by dotted lines; and from the points where these parallels meet the line A B, draw r 4, s 3, t 2, u 1, perpendicular to A B. These perpendiculars transferred to the ordinates k 1, l 2, m 3, n 4, o 5, p 6, q 7, will give the points 1 2 3 4 5 6 7, through which to draw the section.

COVERINGS OF SOLIDS.

A solid angle cannot be formed with fewer than three plane angles. The simplest solid is therefore the pyramid on a base which is an equilateral triangle, and its other three sides formed of similar triangles.

Fig. 331.



The development of this figure (Fig. 331) is made by drawing the triangular base A B C, and then drawing round it the triangles forming the inclined sides.

If the diagram is made on flexible material, such as paper, then cut out, and the triangles folded on the lines A B, B C, C A, the solid figure will be constructed.

Regular Polyhedrons.

These are the *tetrahedron*, or four-sided figure, just described, composed of four equilateral triangles (Fig. 331).

The *hexahedron*, or cube, composed of six equal squares (Fig. 332).

The *octahedron* (Fig. 333), composed of eight equilateral triangles.

The *dodecahedron* (Fig. 334), composed of twelve pentagons.

The *icosahedron* (Fig 335), composed of twenty equilateral triangles.

In the three preceding Figs., A is the elevation, and B the development.

The elements of these solids are the equilateral triangle,

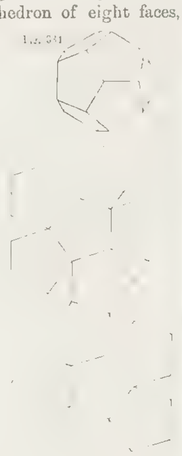
the square, and the pentagon. The irregular polyhedrons may be formed from those named, by cutting off, regularly,

Fig. 332.

Fig. 333.

the solid angles. Thus, in cutting off the angles of the tetrahedron, there results a polyhedron of eight faces, composed of four hexagons and four equilateral triangles. The cutting off the angles of the cube, in the same manner, gives a polyhedron of fourteen faces, composed of six octagons, united by eight equilateral triangles.

Fig. 334.



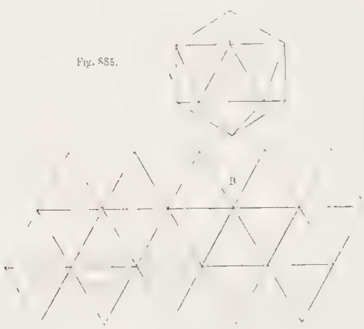
The same operation performed on the octahedron produces fourteen faces, of which eight are hexagonal and six square.

The dodecahedron gives thirty-two sides, namely, twelve decagons, and twenty triangles.

The isocahedron gives thirty-two sides—twelve pentagons and twenty hexagons. This last approaches almost to the globular form, and may be rolled like a ball.

The other solids which have plane surfaces are the *pyramids* and *prisms*. These may be regular or irregular: they may have their axes

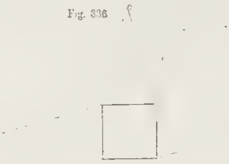
Fig. 335.



perpendicular or inclined: they may be truncated or cut with a section, parallel or oblique, to their base.

The development of a right prism or right pyramid, of which the base and the height are given, offers no difficulty. The operation consists, in the case of the pyramid (Fig. 336), of elevating, on each side of the base, a triangle having its height equal to the inclined height of each side; and in that of the prism (Fig. 337), in raising on each side of the base a rectangle equal to the perpendicular height of the prism; or, otherwise, connecting the sides together, as shown by the dotted lines in both figures.

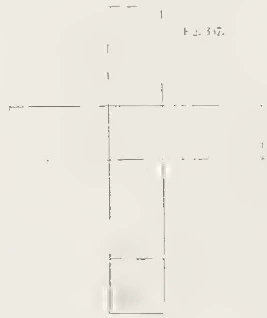
Fig. 336



In an oblique pyramid the development is found as follows:—

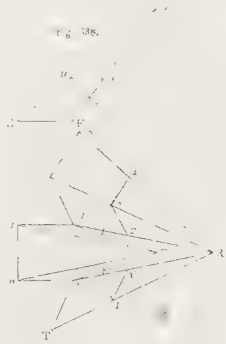
Let $a\, b\, c\, d$ (Fig. 338), be the plan of the base of the pyramid, $a\, b\, c$ P d its horizontal projection, and E F G its side. Then on the side $d\, c$ construct the triangle cRd, making its height equal to the sloping side of the pyramid F G: this triangle is the development of the side d P c of the pyramid. Then from d, with the radius E F, describe an arc O; and from R, with

Fig. 337.



the radius E G, describe another arc intersecting the last at O: join R O, d O; and the triangle d R O will be the development of the side a P d. In the same way, describe the triangle C R T, for the development of the side b P c. From R, again, with the same radius E G, describe an arc S, which intersect by an arc described from O with the radius $a\, b$; and the triangle O R S will be the development of the side a P b.

Fig. 338.



If the pyramid is truncated by a line $w\, a$ parallel to the base, the development of that line is obtained by setting off from R on R c, and R d, the length G a in x and 2, and on R S, R O, and R T, the length G w in 4, 3, 1; and drawing the lines 1 x, x 2, 2 3, 3 4, parallel to the bases of the respective triangles T R c, C R d, d R O, O R S. If it is truncated by a line $w\, y$, perpendicular to the axis, then from the point R, with the radius G w, or G y, describe an arc 1 4, and inscribe in it the sides of the polygon forming the pyramid.

Development of the Coverings of Prisms.

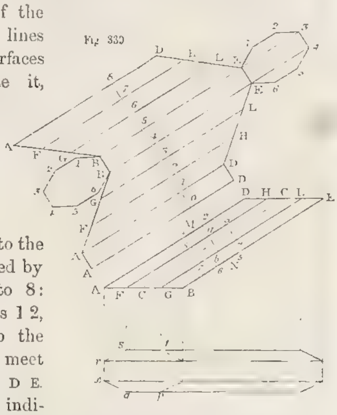
In a right prism, the faces being all perpendicular to the bases which truncate the solid, it results that their

development is a rectangle composed of all the faces joined together, and bounded by two parallel lines equal in length to the contour of the bases.

When a prism is inclined, the faces form different angles with the lines of the contours of the bases: whence there results a development, the extremities of which are bounded by lines forming parts of polygons.

After having drawn the line C C (Fig. 339), which indicates the axis of the prism, and the lines A B, D E, the surfaces which terminate it, describe on the middle of the axis the polygon forming the plan of the prism, taken perpendicularly to the axis, and indicated by the figures 1 to 8: produce the sides 1 2, 6 5, parallel to the axis, until they meet the lines A B, D E. These lines then indicate the four arrises of the prism, corresponding to the angles 1 2 5 6. Through the points 8 3 7 4, draw lines parallel to the axis meeting A B, D E in F H, G L: these lines represent the four arrises 8 3 7 4.

Fig. 339.



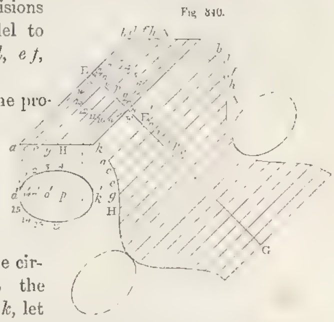
In this profile the sides of the plan of the polygon 1 2 3 4 5 6 7 8 give the width of the faces of the prism, and the lines A D, F H, G L, B E their length. From this profile may be drawn the horizontal projection, in the manner shown by the dotted lines. To trace the development of this prism on a sheet of paper, so that it can be folded together to form the solid, proceed thus:—On the middle of C C raise an indefinite perpendicular M N. On that line set off the width of the faces of the prism, indicated by the polygon, in the points 0 1 2 3 4 5 6 7 8: through these points draw lines parallel to the axis, and upon them set off the lengths of the lines in profile, thus: —From the points 0 1 and 8, set off the length M D in the points D D D; from 2 and 7, set off *a* H in H and H; from 3 and 6, set off *b* L in L and L; and so on: then draw the lines D D, D H L E, E E, E L H D, for the contour of the upper part of the prism. To obtain the contour of the lower portion, set off the length M A from 0 to A, 1 to A, and 8 to A, the length *a* F from 2 and 7 to F, the length *b* G from 3 and 6 to G, and so on; and draw A A, A F G B, B B, B G F A, to complete the contour. The development is completed by making on B B and E E the polygons 1 2 3 4 5 6 B B, 1 2 3 4 5 6 E E, similar to the polygon of the plan *r s t p q x*.

Development of Cylinders.

Cylinders may be considered as prisms, of which the base is composed of an infinite number of sides. Thus we shall obtain graphically the development of a right cylinder by a rectangle of the same height, and of a length equal to the circumference of the circle, which serves as its base, measured by a greater or lesser number of equal parts.

But if the cylinder (Fig. 340) be oblique, and it is required to draw its profile as inclined, describe on the centre of the axis of the inclined profile, and perpendicular to it, the circle or ellipse which forms the base; and divide its circumference into a number of equal parts, and through these divisions draw lines parallel to the axis *a b*, *c d*, *e f*, *g h*, &c.

Fig. 340.



Then to find the projection of the base on a horizontal plane, from the points *a c e g*, where the lines from the divisions of the circumference meet the line of the base *a k*, let fall perpendiculars on a line *a′ k′*, parallel to the base, and produce them indefinitely beyond it. From the points *m′ n′ o′ p′*, where these perpendiculars intersect the line *a′ k′*, set off on each side *m′* 1, *m′* 15, and *n′* 2, *n′* 14, equal to the ordinates of the circle distinguished by the same letters and figures, and so on with the other divisions; and through the points thus obtained, draw the ellipse *a*, 4, *k*, 12, which is the projection of the base of the cylinder on a horizontal plane.

To obtain the development of the cylindrical surface, produce E F indefinitely to G, and set out on it from E′ the divisions of the circumference of the circle 1 2 3 4, &c., in the points *m n o p*, &c.: through these, draw lines parallel to the axis, and transfer to them the lengths of the corresponding divisions of the profile, as E *a*, E *b*, *m c*, *m d*, *ne*, *nf*, &c.; then draw the curves *a c e g* H, *b d f h* A, through the points thus obtained. The addition of the elliptic surfaces, which form the base and head of the solid, and which are similar and equal to *a′*, 4, *k′* 12, completes the development.

The extent E′ G will not be truly the same as that of the periphery of the circle E F, inasmuch as the distances in the latter are but the chords of segments; if, however, the number of divisions employed be ample, the amount of the error will, for practical purposes, be inappreciable.

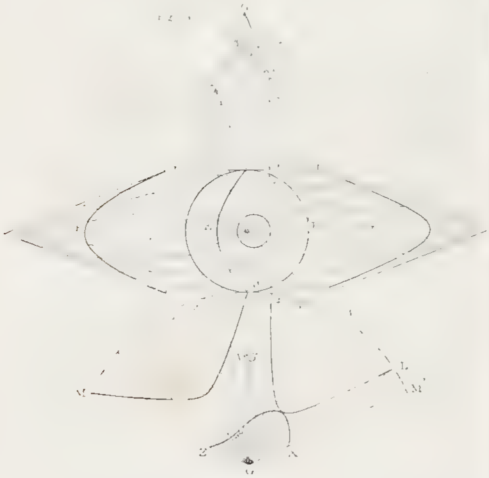
Development of Right and Oblique Cones.

We have considered cylinders as prisms with polygonal bases: for the same reason we may regard cones as pyramids.

In right pyramids, with regular and symmetrical bases, as the lines of the arrises extending from the summit to the base are equal, and as the sides of the polygons forming the base are also equal, their developed surfaces will be composed of similar and equal isosceles triangles, which, as we have seen (Fig. 336, *a b c d*), will, when united, form a part of a regular polygon inscribed in a circle, of which the inclined sides of the polygon form the radii. Thus, in considering the base of the cone K H (Fig. 341) as a regular polygon of an infinite number of sides, its development will be found in the sector of a circle, M′ A F B M″ (No. 3), the radius of which equals the side of the cone K G′ (No. 1), and its arc equals the circumference of the circle forming its base (No. 2).

To trace on the development of the covering, the curves of the ellipse, parabola, and hyperbola, which are the result of the sections of the cone by the lines D I, I G′, E F,

it is necessary to divide the circumference of the base A F B M (No. 2) into equal parts, as 1 2 3 4 5 6, and from these to draw radii to the centre of the circle C″, which is the horizontal projection of the summit; then to carry these divisions to the common intersection line K H, and from their terminations there to draw lines to the summit G′, in the vertical projection No. 1. These lines cut the intersecting planes, forming the ellipse, parabola, and hy-



perbola, and by the aid of the intersections, we obtain the horizontal projection of these figures in No. 2—the parabola passing through M E′ F, the hyperbola through G″ L, and the ellipse being represented by the circle D′ I′.

To obtain points in the circumference of the ellipse upon the development, through the points of intersection *o p q r s*, draw lines parallel to K H, carrying the heights to the side of the cone G′ H, in the points 1 2 3 4 5 6 7, and transfer the lengths G′ 1, G′ 2, G′ 3, &c., to G 1, G 2, G 3, G 4, &c., on the radii of the development in No. 3; and through the points thus obtained draw the curve Z D I X.

To obtain the parabola and hyperbola, proceed in the same manner, by drawing parallels to the base K H, through the points of intersection; and transferring the lengths thus obtained on the sides of the cone G′ K, G′ H, to the radii in the development

The projections in Nos. 4 and 5 do not require explanation.

Development of the Oblique Cone.

In the oblique cone, the position of the summit in the horizontal projection not being coincident with the centre of the circle forming the base, the lines drawn from it to the divisions in the circumference are not radii, and are of unequal lengths. To obtain, therefore, the proper points of intersection, it is necessary to construct a right-angled triangle on each of these lines as a base; then the vertical height of the cone is the other side of the right angle, and its hypothenuse is the side of the cone corresponding to the division. Thus, in Fig. 342 the bases of the right-angled triangles C A, C 1, C 2, &c., are equal to the lines C A, C 1, C 2, &c., in the horizontal projection (Fig. 343); the height of all the triangles is equal to the vertical height of the cone C C′; and the hypothenuse of each triangle is thus easily obtained.

To obtain the development (Fig. 344), take any point C to represent the summit, draw C A, and make it equal to C² A (Fig. 342); then from A, with the length A 1, the first division of the circumference in the horizontal projection (Fig 343), as radius, describe an indefinite arc; and from C, with the hypothenuse $c^2$1 (Fig. 342) as radius, describe another arc, intersecting the first, and the intersection

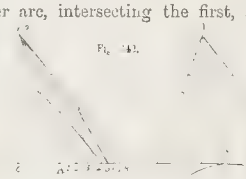


Fig. 342.

gives the point 1 in the development. From this last point, with the constant radius A 1, describe another arc, and intersect it from C by an arc with the second hypothenuse C² 2 (Fig. 342), as radius; and proceed thus till the whole is completed.

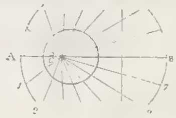


Fig. 343.

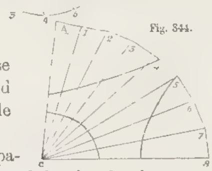


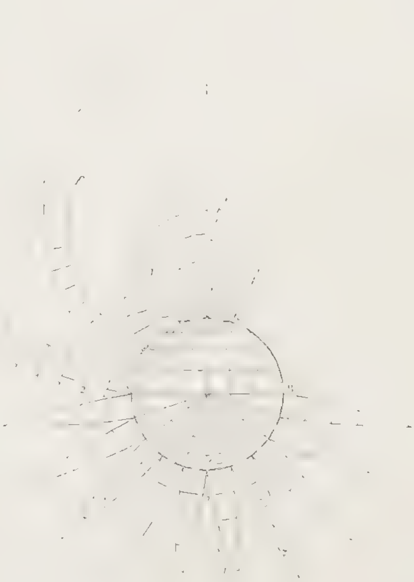
Fig. 344.

The lines of the ellipse, parabola, and hyperbola are found in the development by first obtaining them on the lines of the triangles, in Fig. 342, and then transferring the lengths to the development.

Development of Solids whose Surface is of Double Curvature.

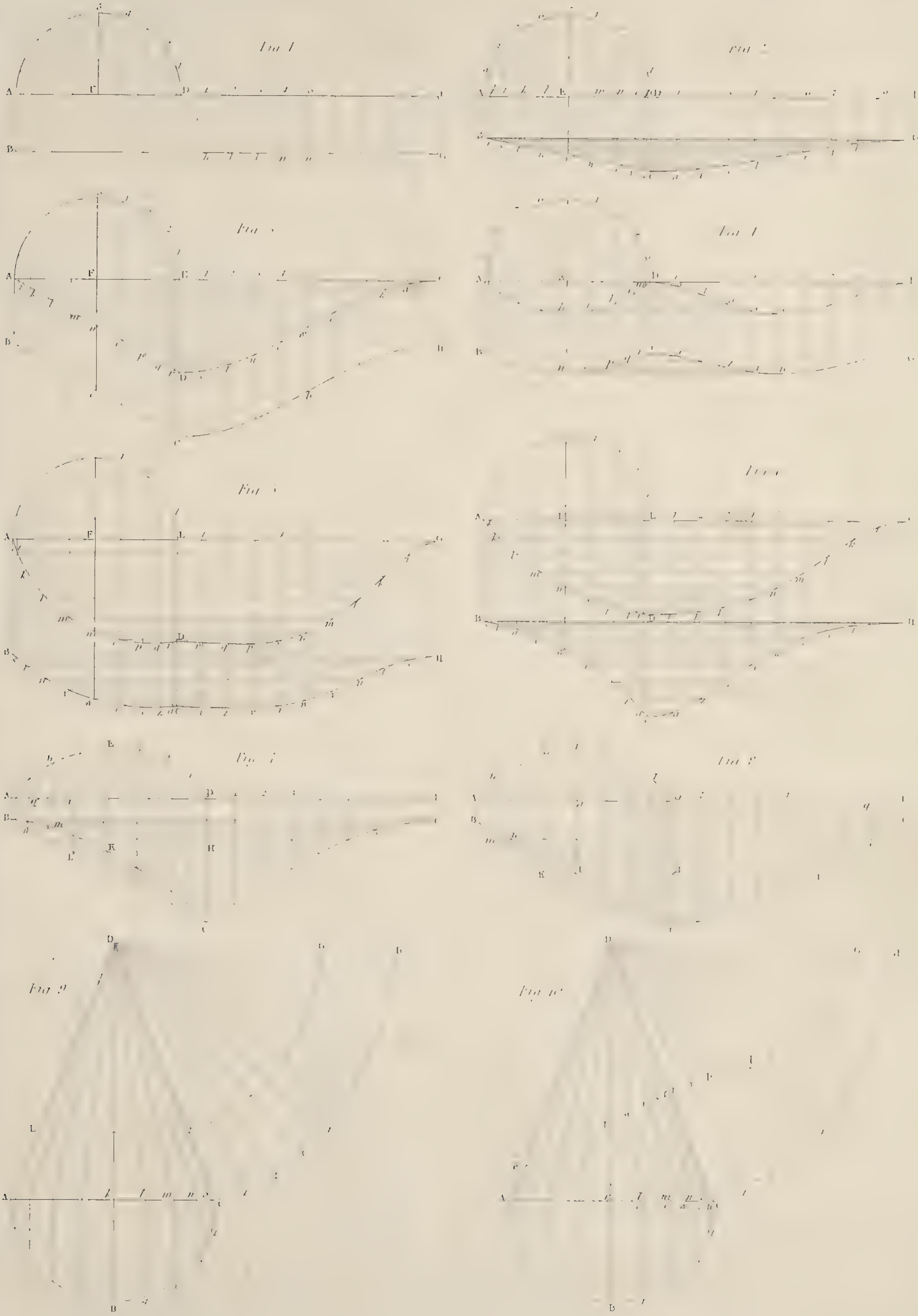
The development of the sphere, and of other surfaces of

Fig. 345.



double curvature, is impossible except on the supposition

COVERINGS OF SOLIDS.



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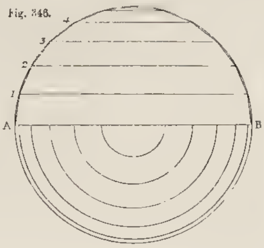
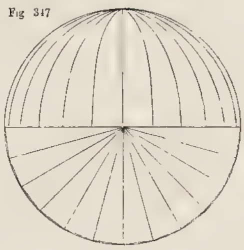
of their being composed of a great number of small faces, either plane, or of a simple curvature, as the cylinder and the cone. Thus a sphere or spheroid may be considered as a polyhedron, terminated, 1st, by a great number of plane faces, formed by truncated pyramids, of which the base is a polygon, as in Fig. 345; 2d, by parts of truncated cones forming zones, as in Fig. 346; 3d, by parts of cylinders cut in gores, forming flat sides, which diminish in width, as in Fig. 347.

Fig. 346.



In reducing the sphere, or spheroid, to a polyhedron with flat sides, two methods may be adopted, which differ only in the manner of arranging the developed faces.

Fig 347



The most simple method is by parallel circles, and others perpendicular to them, which cut them in two opposite points, as in the lines on a terrestrial globe. If we suppose that these divisions, in place of being circles, are polygons of the same number of sides, there will result a polyhedron, like that represented in Fig. 345, of which the half, A D B, shows the geometrical elevation, and the other half, A E B, the plan.

To find the development, first obtain the summits P, q, r, s, of the truncated pyramids, which form the demi-polyhedron A D B, by producing the sides A 1, 12, 23, until they meet the axis E D produced; then from the points P, q, r, and with the radii P A, P 1, q 1, q 2, r 2, r 3, and s 3, s 4, describe the indefinite arcs A B, 1 b, 1 b', 2 f, 2 f', 3 g, 3 g', 4 h, and from D 4 h', upon which set off the divisions of the demi-polygons A E B, and draw the lines to the summits P, q, r, s, and D, from all the points so set out, as A 1 2 3 4 5 B, for each truncated pyramid. These lines will represent for every band or zone the faces of the truncated pyramids of which they constitute a part.

The same development can be made by drawing through the centre of each side of the polygon A E B, indefinite perpendiculars, and setting out upon them the heights of the faces in the elevation, 1 2 3 4 D, and through the points thus obtained drawing parallels to the base. On each of these parallels then set out the widths h, i, k, l, d, of the corresponding faces in the plan, and there will be thus formed trapeziums and triangles, as in the first development, but arranged differently. This method is used in constructing geographical globes, the other is more convenient in finding the stones of a spherical vault.

The development of the sphere by reducing it to conical zones (Fig. 346) is accomplished in the same manner as the reduction to truncated pyramids, with this difference, that the development of the arrises, indicated by A 1 2 3 4, are arcs of circles described from the summits of cones, in place of being polygons.

The development of the sphere reduced into parts of cylinders, cut in gores, is produced by the second method described, but in place of joining by lines, the points E, h, i, k, l, d (Fig. 345), we unite them by a curve, as in Fig. 347. This last method is used in tracing the development of caissons in spherical or spheroidal vaults.

The application of these principles to the cases of coverings which occur most frequently in carpentry, is illustrated in Plates II., III., and IV.

Plates II., III., IV.

To find the covering of a right cylinder.

Plate II.—Let A B C D (*Fig.* 1) be the seat or generating section. On A D describe the semicircle A 5 D, representing the vertical section of half the cylinder, and divide its circumference into any number of equal parts, 1 2 3 4 5, &c., and transfer those divisions to the lines A D and B C produced; then the parallelogram D C, G F will be the covering required.

To find the edge of the covering when it is oblique in regard to the sides of the cylinder.

Let A B C D (*Fig.* 2) be the seat of the generating section, the edge B C being oblique to the sides A B, D C: draw the semicircle A 5 D, and divide it into any number of parts, as before; and through the divisions draw lines at right angles to A D, producing them to meet B C in r s t u v, &c. Produce A D, and transfer to it the divisions of the circumference, 1 2 3 4 5 6, &c.; and through them draw indefinitely the lines 1 a, 2 b, 3 c, perpendicular to D F: to these lines transfer the lengths of the corresponding lines intercepted between A D and B C, that is, to 1 a transfer the length p z, to 2 b transfer o y, and so on, by drawing the lines z a, y b, x c, &c., parallel to A F, the intersections; then shall D F C G be the development of the covering of A B C D.

To find the covering of a semi-cylindric surface contained between two parallel planes perpendicular to the generating section.

Let A B C D (*Fig.* 3) be the seat of the generating section: from A draw A G perpendicular to A B, and produce C D to meet it in E: on A E describe the semicircle, and transfer its perimeter to E G, by dividing it into equal parts, and setting off corresponding divisions on E G. Through the divisions of the semicircle draw lines at right angles to A E, producing them to meet the lines A D and B C, in i k l m, &c. Through the divisions on E G draw lines perpendicular to it; then through the intersections of the ordinates of the semicircle, with the line A D, draw the lines i a, k z, l y, &c., parallel to A G, and where these intersect the perpendiculars from E G, in the points a, z, y, x, w, v, u, &c., trace a curved line G D, and draw parallel to it the curved line H C; then will D C, H G, be the development of the covering required.

To find the covering of a semi-cylindric surface bounded by two curved lines.

Figs. 4, 5, 6.—The construction to obtain the developments of these coverings is precisely similar to that described in *Fig.* 3, as will be evident on inspection.

To form the edge of a cylindric surface terminated by a curved line, so that when the envelope is applied to the surface its edge may coincide with a plane passing through three given points.

Let A E D (*Figs.* 7 and 8), be the base of the solid. Draw

A B and D C perpendicular to A D, and make A B equal to the height of the point whose seat is A, and D C equal to the height of the point whose seat is D. On D C make H equal to the height of the point whose seat is E: join B C. Draw H L (*Fig.* 7) parallel to A D and H K (*Fig.* 8), cutting B C in L. Draw L *a* parallel to D C, cutting A D in *a*: join *a* E. Divide the arc of the base into any number of equal parts in 1, 2, 3, 4, &c., and extend them on A D produced to F. Then to find any point in the envelope—suppose that which corresponds to *b* on the seat. Draw *b q* parallel to *a* E, cutting A D at *q*; draw also *q n* parallel to D C, cutting B C in *n*. Make *q′ o* equal to *q n*, and *o* is a point in the line required. Proceed in the same manner with other points until the line C *o* G (*Fig.* 7) and C L *o* G (*Fig.* 8) is obtained.

To find the covering of the frustum of a cone, the section being made by a plane perpendicular to the axis.

Let A C E F (*Fig.* 9) be the generating section of the frustum. On A C describe the semicircle A B C, and produce the sides A E and C F to D. From the centre D, with the radius D C, describe the arc C H; and from the same centre, with the radius D F, describe the arc F G: divide the semicircle into any number of equal parts, and run the same divisions along the arc C H; draw the ordinates to the semicircle through the points of division, at right angles to, and meeting A C; and from the points *o n m*, &c., where these ordinates cut the line A B, draw lines to the point D; and from the last division in the arc C H, draw also a line to the point D; then shall C H G F be half the development of the covering of the frustum A C F E.

To find the covering of the frustum of a cone, the section being made by a plane not perpendicular to the axis.

Let A C F E (*Fig.* 10) be the frustum. Proceed as in the last problem to find the development of the covering of the semicone: then, to determine the edge of the covering on the line E F. From the points *p q r s t*, &c., draw lines perpendicular to E F, cutting A C in *y x w v u*; and the length *u t* transferred from 1 to *a*, *v s* transferred from 2 to *b*, and so on, will give *a b c d e* G, points in the edge of the covering.

To find the covering of the frustum of a cone, when cut by two cylindric surfaces perpendicular to the generating section.

PLATE III.—Let A E F C (*Fig.* 1) be the given section, and A *k* C, E *p* F, the lines on which the cylindrical surfaces stand. Produce A E, C F, till they meet in the point D. Describe the semicircle A B C, and divide it into any number of equal parts, and transfer the divisions to the arc C H, described from D, with the radius D C. Through the divisions in the semicircle 1 2 3 4, draw lines perpendicular to A C, and through the points where they intersect A C draw lines to the summit D. Draw lines also through the points 1 2 3 4 5, &c., of the arc C H, to the summit D; then through the intersections of the lines, from A C to D, with the seats of cylindrical surfaces *k l m n o*, and *p q r s t*, draw lines parallel to A C, cutting C D; and from the points of intersection in C D, and from the centre D, describe arcs cutting the radial lines in the sector D C H in *u v w x y*, and *a b c d e*; and curves traced through the intersections will give the form of the covering.

To find the development or covering of the surface of the frustum of a scalene semicone.

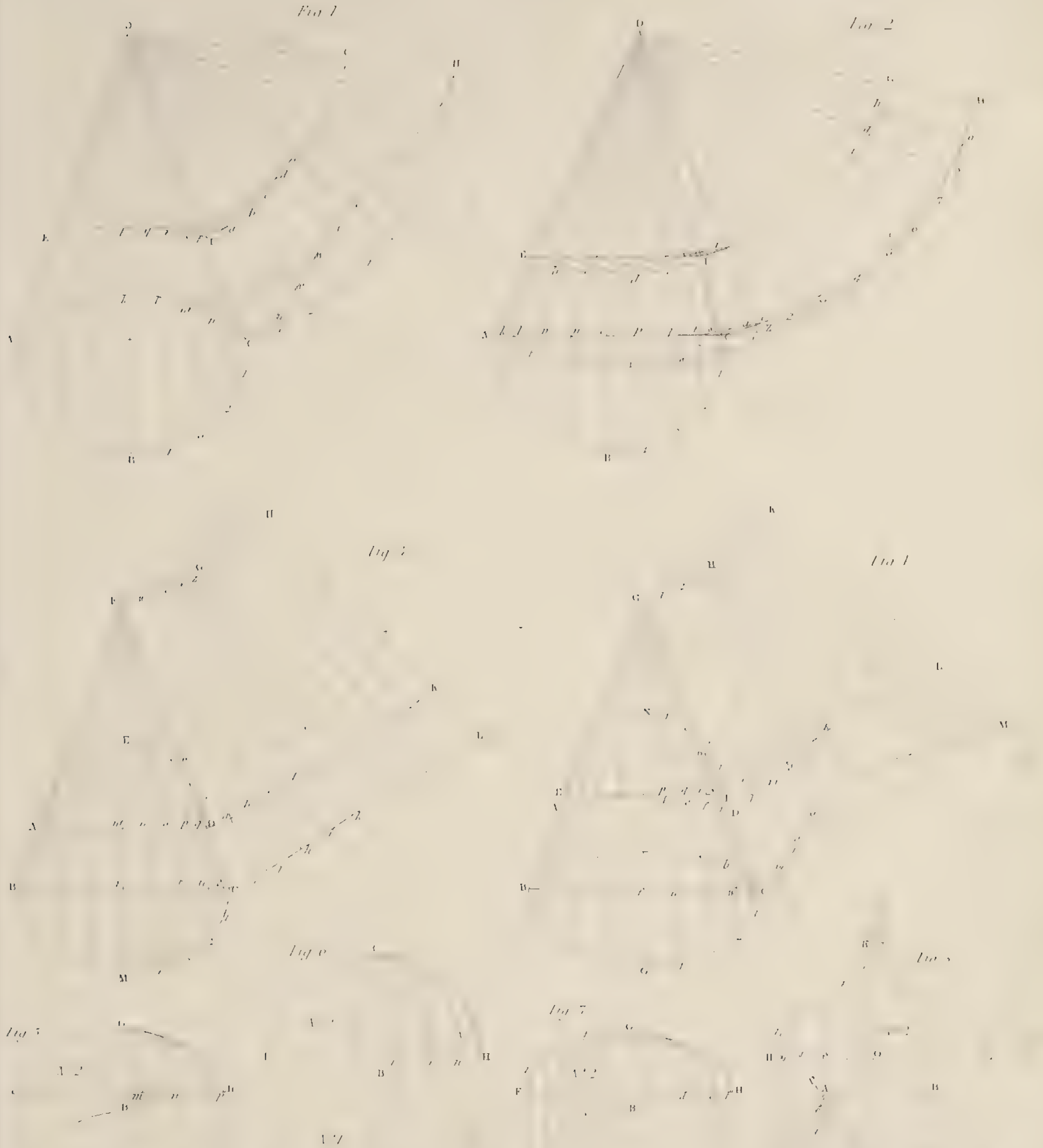
Let A B C (*Fig.* 2) be the base of the semicone; A C D the plane of its section, cut on the line A C, perpendicular to the base; and let A C E F be the seat of the envelope required. Divide A B C into any number of equal parts, as in 1 2 3, &c.; and from the points of division draw lines perpendicular to A C, cutting it in *k l m*, &c.; and from these points draw right lines to D. To find the true lengths of the lines radiating from D, the vertex of the cone, to the points 1 2 3 4 B, in the circumference of the base:—from the point *s*, where D *s* cuts A C, draw *s a* perpendicular to D *s*, and from *r* draw *r a′* perpendicular to D *r*, draw also *q z* perpendicular to D *q*, *p y* perpendicular to D *p*, *o x* perpendicular to D *o*, *n w* to D *n*, *m v* to D *m*, *l u* to D *l*, and *k t* to D *k*. Then make *s a* equal to *s* 1, *r a* equal to *r* 2, *q z* equal to *q* 3, &c.; draw the dotted lines D *t*, D *u*, D *v*, D *w*, D *x*, D *y*, D *z*, D *a*, D *a′*, which will give the respective lengths of the corresponding lines on the envelope of the semicone, as shown by the concentric dotted arcs *t* 9, *u* 8, *v* 7, *w* 6, &c., described from the point D. With distances exactly equal to the divisions C 1 2 3 4 B of the arc A B C, set off from C the points 1 2 3 4 5, &c., to H, on the corresponding concentric dotted lines, so as that D H will be equal to D A, D 9 equal to D *t*, D 8 equal to D *u*, &c.; then draw the curved line C H through the points thus found. The curved line F G, forming the inner line of the envelope, is found, in like manner, by drawing the perpendicular lines *b*, *c*, *d* from the lines D *k*, D *l*, D *m*, &c., to their corresponding dotted lines. Then H G will be made equal to A E, 9 *h* to *t b*, 8 *g* equal to *u c*, 7 *f* equal to *v d*, &c. Then the curve being drawn through the points thus found, the figure F G H C is the development of the portion of the cone shown by the lines A C E F.

To find the envelope for the frustum of a cuneoid.

Let A B C D (*Fig.* 3) be the seat of the portion of the surface to be covered; the semicircle A E D the section of the lesser end; and the semi-ellipse, B M C, of the greater end; each being of the same altitude, that is, *m* E being equal to *r* M. Produce B A, C D, to meet in F, and divide the semicircle A E D into any number of equal parts, as in 1, 2, 3, 4, E. From these points draw the lines 1 *q*, 2 *p*, 3 *o*, &c., perpendicular to A D; and from F through *m n o p q* draw right lines cutting B C in *r s t u v*: from these points draw *v* 1, *u* 2, *t* 3, &c., perpendicular to B C, and cutting the semi-ellipse in 1 2 3 4, &c. Draw F G perpendicular to F C; on F G make F *w* equal to *q* 1, F *x* equal to *p* 2, F *y* equal to *o* 3, F *z* equal to *n* 4, F G equal to *m* E. From D, with a radius equal to D 1, describe the arc at *a*, and draw *w f* tangent to that arc: make *w a* equal to F *q*, and *a f* equal to *q v*. From *a*, with the radius D *a*, describe the arc at *b*, and draw *x g* tangent to that arc: make *x b g* equal to F *p u*. From *b*, with the radius D *a*, describe the arc at *c*, and draw the tangent; and proceed with this and the other divisions as before. Then through the points D *a b c d e* and C *f g h i k*, draw the curved lines completing one half of the envelope: the other half joined on the same base, is equal and similar; and may be described thus:—From G as a centre describe concentric circles from *w x y z*, and from the same centre describe with any convenient radius an arc, as 6 5 7: make the divisions on 5 7 equal to the divisions on 5 6: make 7 H equal to 6 F, and join G H. The remainder of the operation does not require to be described.

To find the envelope of a portion of a cuneoid contained

COVERINGS OF SOLIDS.



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between two cylindric surfaces, the axes of which are perpendicular to the plane passing through the axis of the cuneoid.

Fig. 4.—Find, in the manner shown and described in the last example, the dotted curved line F *h i k*, corresponding to one half of the semicircle E N F; find also the dotted curved line C M, corresponding to the circumference of the semi-ellipse B O C; and having completed the development of the covering, as if for the frustum bounded by the lines B E F C, proceed as follows:—The line E F being a tangent to the line A D, and parallel to the chord B C, make *h l*, *i m*, &c., respectively equal to *s g*, *r f*, *q e*, &c., and draw the curve D *l m y k*; then form the inner edge of the envelope. Then make *l n* equal to *g c*, *m o* equal to *f b*, *y x* equal to *e a*, &c., and through C *n o x*, &c., draw the outer edge of the envelope.

To find the covering of a segmental dome.

Fig. 5.—No. 1 is the plan, and No. 2 the elevation of a segmental dome. Through the centre of the plan E draw the diameter A C, and the diameter B D perpendicular to A C, and produce B D to I. Let D E represent the base of a semi-section of the dome; upon D E describe the arc D *k* with the same radius as the arc F G H (No. 2); divide the arc D *k* into any number of equal parts 1 2 3 4 5, and extend the divisions upon the right line D I, making the right line D 1 2 3 4 5 I equal in length, and similar in its divisions, to the arc D *k*: from the points of division 1 2 3 4 5 in the arc D *k*, draw lines perpendicular to D E, cutting it in the points *q r s*, &c. Upon the circumference of the plan No. 1, set off the breadth of the gores or boards *l m*, *m n*, *n o*, *o p*, &c.; and from the points *l m n o p* draw right lines through the centre E: from E describe concentric arcs *q v*, *r u*, *s t*, &c., and from I describe concentric arcs through the points D 1 2 3 4 5: *l m* being the given breadth at the base, make 1 *w* equal to *q v*, 2 *x* equal to *r u*, 3 *y* equal to *s t*, &c.; draw the curve line through the points *l w x y*, &c., to I, which will give one edge of the board or gore to coincide with the line *l* E. The other edge being similar, it will be found by making the distances from the centre line D I respectively equal. The seat of the different boards or gores on the elevation are found by the perpendicular dotted lines *p p*, *o o*, *n n*, *m m*, &c.

To find the covering of a semicircular dome.

Fig. 6, Nos. 1 and 2.—The procedure here is more simple than in the case of the segmental dome; as the horizontal and vertical sections being alike, the ordinates are obtained at once.

To find the covering of an ellipsoidal dome.

Let A B C D (*Fig.* 7) be the plan, and F G H the elevation of the dome. Divide the elliptical quadrant F G (No. 2), into any number of equal parts in 1 2 3 4 5, and draw through the points of division lines perpendicular to F H, and produced to A C (No. 1), meeting it in *i k l m n*: these divisions are transferred by the dotted arcs to the gore *b* E *c*, and the remainder of the process is as in the two last examples.

To find the covering of an ogee dome, hexagonal in plan.

Let A B C D E F (No. 1, *Fig.* 8) be the plan of the dome, and H K L (No. 2), the elevation, on the diameter F C. Divide H K into any number of equal parts in 1 2 3 4 5 K, and through these draw perpendiculars to H L, and produce them to meet F C (No. 1), in *l m n o p* G. Through the points of meeting *l m n o p*, draw lines *l d*, *m e*, *n f*, &c., parallel to the side F E of the hexagon: bisect the side F E in N, and draw G N, which will be the seat of a section of the dome, at right angles to the side E F. To find this section nothing more is required than to set up on N G, from the points *t u v*, &c., the heights of the corresponding ordinates *q* 1, *r* 2, *s* 3, &c., of the elevation (No. 2), to draw the ogee curve N 1 2 3 4 5 P, and then to use the divisions in this curve to form the gore or covering of one side E *g h k* M D.

To find the covering of a circular dome when it is required to cover the dome horizontally.

PLATE IV.—Let A B C (*Fig.* 1) be a vertical section through the axis of a circular dome, and let it be required to cover this dome horizontally. Bisect the base in the point D, and draw D B E perpendicular to A C, cutting the circumference in B. Now divide the arc B C into equal parts, so that each part will be rather less than the width of a board; and join the points of division by straight lines, which will form an inscribed polygon of so many sides; and through these points draw lines parallel to the base A C, meeting the opposite sides of the circumference. The trapezoids formed by the sides of the polygon and the horizontal lines, may then be regarded as the sections of so many frustums of cones; whence results the following mode of procedure, in accordance with the introductory illustration at page 73, and Fig. 346:—produce, until they meet the line D E, the lines *n f*, *f g*, &c., forming the sides of the polygon. Then to describe a board which corresponds to the surface of one of the zones, as *f g*, of which the trapezoid is a section,—from the point *h*, where the line *f g* produced meets D E, with the radii *h f*, *h g*, describe two arcs, and cut off the end of the board *k* on the line of a radius *h k*. The other boards are described in the same manner.

To find the covering boards of an ellipsoidal dome.

Let A B C D (No. 1, *Fig.* 2), be the plan of the dome, and F G H (No. 2) the vertical section through its major axis. Produce F H indefinitely to *n*; divide the circumference, as before, into any number of equal parts, and join the divisions by straight lines. Then to describe any board, produce the line forming one of the sides of the polygon, such as *l m*, to meet F *n* in *n*; and from *n*, with the radii *n m*, *n l*, describe two arcs forming the sides of the board, and cut off the board on the line of the radius *n o*. Lines drawn through the points of the divisions at right angles to the axis, until they meet the circumference A D C of the plan, will give the plan of the boarding.

To find the covering of an ellipsoidal dome in gores.

The principle in this being the same as in the globe, page 72, Fig. 345, we shall merely describe the method of procedure. Let the ellipse A B C D (*Fig.* 3, No. 1) be the plan of the dome, A C its major and B D its minor axis; and let A B C (No. 2) be its elevation. Then, first, to describe on the plan and elevation the lines of the gores, proceed thus:—Through the line A C (*Fig.* 1) produced at H, draw the line E G perpendicular to it, and draw B E D G parallel to the axis A C, cutting E G; then will E G be the length of the axis minor, on which is to be described the semicircle E F G, representing a section of the dome on a vertical plane passing through the axis minor.

Divide the circumference of the semicircle into any number of equal parts, representing the widths of the covering boards on the line B D; and through the points of division

1 2 3 4 5, draw lines parallel to the axis A C, cutting the line B D in 1 2 3 4 5. Divide the quadrant of the ellipse C D (No. 1) into any number of equal parts in *e f g h*; and through these points draw the lines *e a*, *f b*, *g c*, *h d*, in both figures perpendicular to A C, and these lines will then be the seats of vertical sections through the solid, parallel to E F G. Through the points *e f g h* (No. 1), also, draw lines parallel to the axis A C, cutting E G in *o n m k*; and from H, with the radii H *o*, H *n*, H *m*, H *k*, describe the concentric circles *o* 9 9 *p*, *n* 8 8 *q*, *m z y r*, &c. To find the diminished width of each gore at the sections *a e*, *b f*, *c g*, *d h*:—Through the divisions of the semicircle 1 2 3 4 5 draw the radii 1 *s*, 2 *t*, 3 *u*, 4 *v*, 5 *w*, 6 *x*; then by drawing through the intersections of these radii with the concentric circles, lines parallel to H C, to meet the section lines corresponding to the circles, the width of the gores at each section will be obtained; and curves drawn through these points will give the representation of the lines of the gores on the plan.

In No. 2 the intersections of the lines are more clearly shown. The quadrant E G F is half the vertical section on D B, and is divided as in No. 1. The parallel lines 5 5, 4 4, 3 3, show how the divisions of the arc of the quadrant are transferred to the line D B, and the other parallels *a h*, *b k*, *c l*, *d m*, are drawn from the divisions in the circumference of the ellipse to the line E G, and give the radii of the arcs *m n*, *l o*, *k p*, *h q*.

To describe one of the gores, draw any line A B (No. 3), and make it equal in length to the circumference of the semi-ellipse A D C, by setting out on it the divisions 1 2 3 4 5, &c., corresponding to the divisions of the ellipse: draw through those divisions lines perpendicular to A B. Then from the semicircle (No. 1), transfer to these perpendiculars the widths 6 5 to *g n*, 9 9 to *f m*, 8 8 to *e l*, *y z* to *d k*, and *x w* to *c h*, and join A *c*, *c d*, *d e*, *e f*, *f g*, and A *h*, *h k*, *k l*, *l m* and *m n*; which will give the boundary lines of one half of the gore, and the other half is obtained in the same manner.

To describe the covering of an ellipsoidal dome with boards of equal width.

Let A B C D (No. 1, *Fig.* 4) be the plan of the dome, A B C (No. 2) the section on its major axis, and L M N (No. 3), the section on its minor axis. Draw the circumscribing parallelogram of the ellipse F G H K (No. 1), and its diagonals F H G K. In No. 2 divide the circumference into equal parts 1 2 3 4, representing the number of covering boards, and through the points of division 1 8, 2 7, &c., draw lines parallel to A C. Through the points of division draw 1 *p*, 2 *t*, 3 *x*, &c., perpendicular to A C, cutting the diagonals of the circumscribing parallelogram of the ellipse (No. 1), and meeting its major axis in *p t x*, &c. Complete the parallelograms, and their inscribed ellipses corresponding to the lines of the covering, as in the figure. Produce the sides of the parallelograms to intersect the circumference of the section on the transverse axis of the ellipse in 1 2 3 4, and lines drawn through these, parallel to L N, will give the representation of the covering boards in that section. To find the development of the covering, produce the axis D B, in No. 2, indefinitely. Join by a straight line the divisions 1 2 in the circumference, and produce the line to meet the axis produced; and 1 2 *e k g* will be the axis major of the concentric ellipses of the covering *i f g*, 2 *h k*. Join also the corresponding divisions in the circumference of the section on the minor axis, and produce the line to meet the axis produced; and the length of this line will be the axis minor of the ellipses of the covering boards.

To find the covering of an annular vault.

Let A C K G E F A (*Fig.* 5) be the generating section of the vault. On A C describe a semicircle A B C, and divide its circumference into equal parts, representing the boards of the covering: from the divisions of the semicircle *b m t*, &c., let fall perpendiculars on A C, and cutting it in *r s*, &c.; from the centre D of the annulus, with the radii D *r*, D *s*, &c., describe the concentric circles *s q*,&c., representing the covering boards in plan. Through the centre D draw H K perpendicular to G C, indefinitely extending it through K. Join the points of division of the semicircle A *b*, *b m*, *m t*, by straight lines, and produce them until they cut the line K H, as *m b n*, *t m u*, when the points *n*, *u*, &c., are the centres from which the curves of the covering boards *m o*. *t v*, &c, are described.

STEREOGRAPHY—DESCRIPTIVE CARPENTRY.

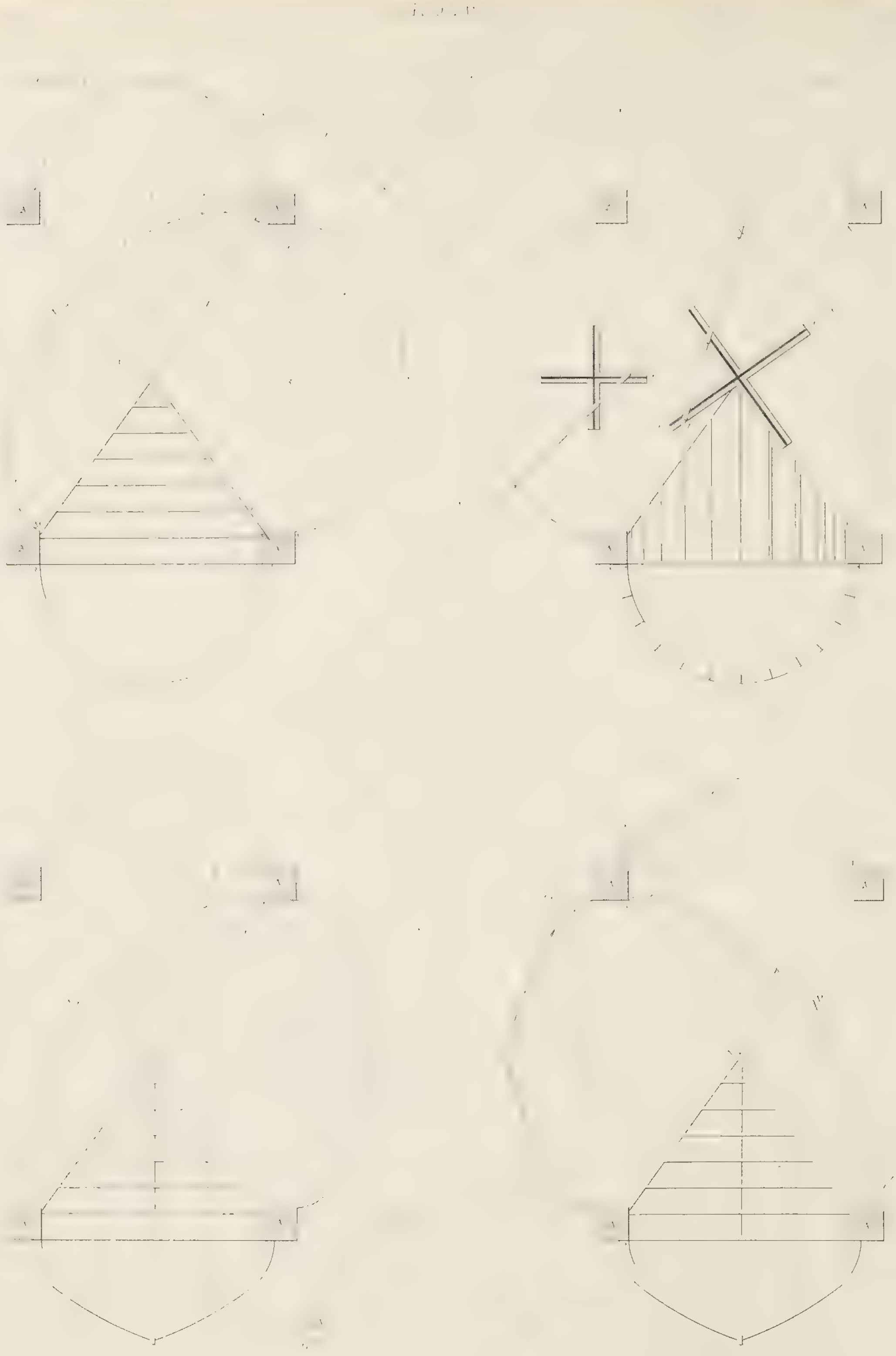
Descriptive Carpentry is the application of the principles of stereography to carpentry, and has this special difference that, while in stereography the bodies which are the subjects of its operations are entire solids, in descriptive carpentry the bodies are made in ribs disposed in parallel lines or planes, or disposed in lines tending to a point, or in planes tending to an axis. Descriptive carpentry shows thus the method of forming the separate pieces in order to construct the whole body or solid.

GROINS.

A groin is the line made by the intersection of arched vaults crossing each other at any angle.

When two cylindric vaults of equal span and height cross, they produce cylindric groins: the intersection of equal cones produces conic groins; of equal spheres, spheric groins.

When the intersecting vaults are of different span and width, the larger is called the body range, and a compound word is used to denote the resultant groin. The term for the vault of the body range is made to end in *o*; as, for instance, in the case of the body range being a cylindrical vault, it would become *cylindro*, a spherical vault would be *sphero*, and the intersecting vault would be *cylindric* or *spheric*, as the case might be. Thus a cylindro-cylindric groin is one formed by a cylindrical body range, and a cylindrical intersecting vault of smaller size. A cylindro-spheric groin is the intersection of a sphere with a cylinder of greater span and height; while a sphero-cylindric groin, is formed by the intersection of a cylindric



vault with a spherical vault of greater dimensions. The curved surface between two adjacent groins is called a sectroid.

PLATES V., VI., VII., VIII., IX., X.

PROBLEM I.—*In a rectangular groined vault, in which the openings are of different widths, but of the same height, and when one of the arches and the seats of the groins are given, to find the arch of the other opening, the groin arch, and the covering of the vaults.*

PLATE V.—Let A A A A (*Fig.* 1, No. 1) be the plan of the piers, B C D the given arch, and O L M, P L Q the seats of the groins. The given arch is in this case a semicircle. Divide the quadrant of the given arch, D C, into any number of equal parts, as 1 2 3 4 5, and from the points of division draw the lines 5 *a*, 4 *b*, 3 *c*, &c., parallel to the axis C E L, to meet the seat of the groin line L O. From the points L *a b c*, &c., draw the line L K G (the axis of the other vault), and *a p* 5, *b o* 4, &c., parallel to these, and make the lines *l* 1, *m* 2, *n* 3, *o* 4, *p* 5 and K G, equal to the ordinates *k* 1, *i* 2, *h* 3, *g* 4, *f* 5, and E C, respectively; then a curve traced through the points F 1 2 3 4 5 G, will give a quadrant of the other arch.

To find the curve of the groin:—From the intersections of the lines C L 5 *a*, &c., with the seat of the groin M L O, draw the perpendiculars *e* 1, *d* 2, *c* 3, &c., and make them equal to the corresponding ordinates *k* 1 or *l* 1, *i* 2 or *m* 2, &c., and trace the curve through the points 1 2 3. By drawing lines through the points 1 2 3 in these quadrants parallel to their major axes, and making *q s*, *r t*, and *v x*, *u w*, equal to *q* 1, *r* 2, and *v* 1, *u* 2, respectively, and continuing the curve through the points so obtained, the arches may be completed.

To find the covering of the smaller sectroid B P L O D:—On any straight line A B (No. 2), set off the divisions 1 2 3, &c., equal to, and corresponding to the divisions of the quadrant D C. Through these divisions draw the perpendiculars A E, 1 *g*, 2 *h*, 3 *i*, and make D C equal to E L, 5 *l* to *f a*, 4 *k* to *g b*, and so on; and through the points C *l k i h g* E draw a curve, and the figure A E C D will be the covering of the half sectroid B P L E: by proceeding with the other ordinates *m n*, &c., in the same manner, the other half of the covering, D C F B, will be obtained.

To find the covering of the larger sectroid F O L Q H:—On any line B C (No. 3), set off the divisions 1 2 3 corresponding to the divisions 1 2 3 of the greater arch F G H (No. 1); draw the perpendiculars 1 *g*, 2 *h*, &c., as before, making them equal to the lines *l e*, *m d*, *n c*, &c., in No. 1; and draw a curve through the points A *g h i k l* E: proceed in the same way with the ordinates *m o*, *n p*, &c., of the other half; and the result will be the figure B A E D C, which is the development of the covering of the sectroid as required.

It will be observed that the angle rib is shown as composed of two thicknesses of stuff. It is bevelled each way so as to range with both branches of the groin. One of the thicknesses is shown on somewhat a larger scale, at No. 4, in which D is the plan, the bevel being obtained on the plan No. 1, at Q. When the two thicknesses are put together, the bevelled face *k* A *g* will range with the surface of the sectroid M L K, and the bevelled face of the other half of the rib with the surface of the sectroid Q L F.

The method of finding the places and lengths of the ribs is shown in the lower part of No. 1. From the seat of any rib, as *a b*, draw the lines *a c*, *b d*; then from *c* to *d* will be the rib *a b*.

The curve of the larger arch, and of any groin arch in a rectangular vault, such as the case illustrated, can be very readily obtained by means of an elliptograph or trammel, as shown in *Fig.* 2. In drawing the curve of the larger arch, the line F H is bisected, and the perpendicular *g f* G drawn: the trammel *d g l f* is then placed with its centre on the intersection of the lines, and its limbs centrally upon these: the distance between the tracer *a* and the stud *c* of the moveable bar is made equal to half the axis major of the ellipse, that is, half of F H; and that between the tracer and the stud *b* equal to the height of the arch or semi-axis minor. The distance between the studs is thus equal to the difference between the major and minor axes of the ellipse. In the same way the groin arch is trammelled, the instrument being adjusted so that from the tracer *n* to the first stud *o* the length is equal to the height of the arch, and to the other stud *p* equal to half the span.

A substitute for the trammel can be formed readily by using a square in place of the cross, and a slip of wood for the sweep. The square is placed on the axes, as shown in Fig. 161, p. 24; two bradawls being thrust through in place of the studs, and another used to supply the place of the tracer: by keeping the bradawls pressed against the limbs of the square whilst the sweep is moving, a quadrant of an ellipse will be formed.

In the Gothic groin (*Fig.* 3) the curve of the diagonal is found by ordinates in the same manner as the one described.

Let A A A A be the piers, as before, B C D the given arch, and K N L the seat of the groin: divide the quadrant D C into any number of equal parts, and draw from the divisions the lines 1 *k e*, 2 *i d*, &c., meeting the seat of the groin in *e d c b a*; then find the larger arch, as before, by drawing the ordinates *e l* 1, *d m* 2, *c n* 3, making them equal to the ordinates of the given arch. To find the curve of the groin from the points on the seat of the groin *e d c b a*, draw the perpendiculars *e* 1, *d* 2, *c* 3, *b* 4, *a* 5, and N M, and make these ordinates equal to the corresponding ordinates of the given arch. This operation gives only one-half of each arch; therefore, in order to complete the arches, draw from the points 1 2 3, the lines 1 *q r* and 1 *s t*, and the other lines parallel to the lines F H K L in the larger arch and groin arch respectively, and set off on them from the centre line the points of the curve. The lengths and places of the ribs are found, as before, by drawing from the seat of any rib, as *u v*, lines to the section of the arch *a y b* at *w* and *x*.

In *Fig.* 4 is illustrated the manner of finding the arches of a Gothic groin by intersecting lines, as explained in Figs. 206, 207, p. 30.

Let A A A A be the piers, B C D the given arch, and K N L the seat of the groin. Set up the height of the large arch I G, and of the groin arch N M, each equal to the height of the given arch, and from B, F, and K draw the perpendiculars B *v*, F *z*, and K *z*. Join B C, and divide the line into any number of equal parts 1 2 3 4 C; from E draw lines through the divisions 1 2 3 4 to the circumference of the arc in the points *o p q r*, and through these points draw lines from C, cutting the perpendicular B *v* in *s t u v*. Then to find the

large arch, join G F, and divide it into the same number of equal parts as the line B C in the given arch. From I draw lines through the points of division; then transfer the divisions of the perpendiculars B *v* in the given arch to the perpendicular F *z* in the large arch, at *s t u z*; and from G draw lines to these divisions, intersecting the lines drawn from I. The intersections give points through which the curve is to be traced. Proceed in the same way in drawing the groin arch: divide the line K M into the same number of parts as B C; draw through the divisions the lines N *e*, N *f*, N *g*, N *h*; and intersect these by lines drawn from M to the divisions *s t u z*, on the perpendiculars K *z*, transferred from B *v*. The intersections give points in the curve.

The lengths and places of the ribs are found as before, by drawing from the seat of any rib, *k l*, lines to the section *o p q*, when *m p* gives the place of the rib, and *m p n* its length.

To draw the side arches and groin arches in a Gothic vault, where the side arches are of the same height as the arch of the body range.

PLATE VI. *Fig.* 1., Nos. 1 and 2.—Let A B (No. 1) be the centre of the body range, and E D C the given arch; F G H, K L M side arches, of different spans but the same height; O Q the seat of the smaller, and S U the seat of the larger groin: divide the arch C D, as before, into any number of equal parts, through which draw lines parallel to the axis of the body range A B: from the points of intersection *e f g h* with the seat of the groins O Q and S U, raise perpendiculars to these lines *e* 1, *f* 2, &c.; and from the same points draw lines *e a* 1, *f b* 2, &c., perpendicular to the chords of the arches F I H and K N M. Then from the points *e f g h* and *a b c d* set off the lengths of the ordinates of the given arch, to give the curve of the arches required. No. 2 is a vertical section through the axis of the body range, showing the timbers of the vaults; and on the under side of the plan No. 1 is shown the method of finding the diagonal ribs R Q, V U.

Given the arch of the body range of a groined vault, with the imposts on an inclined line: to find the side and groin arches.

Let A B C (*Fig.* 2) be the given arch, I L K the seat of the groin, and E H G the inclination of the imposts, making the angle G E *o* with the horizon. Proceed by dividing the arch A B C into equal parts in 1 2 3 4, and drawing ordinates from them, as before, meeting the seat of the groin in *e f g h* L; then draw from these points the lines *e a* 1, *f b* 2, *g c* 3, &c., perpendicular to the line *a o*, and set up thereon from the points *a b c d* H, where they intersect the raking line E G, ordinates *a* 1, *b* 2, &c., corresponding to those in the given arch; then through the points found, trace the curve of the arch E F G. To find the curve of the groin, draw K N perpendicular to I K, and equal to *o* G, expressing the rake or inclination of the groin; join I N; draw the lines *e i* 1, *f k* 2, *g l* 3, &c., perpendicular to I K, and upon them set off from *i k l m*, on the line I N, the heights 1 2 3 4, &c., of the ordinates of the body range A B C.

To draw the groin rib when the highest point of the side arch is not in the middle of its width, as in U V D, *right-hand side of Fig.* 2.

Divide the body rib Q R S into equal parts in 1 2 3 4, and through the points of division draw lines parallel to Q S, to meet the line P *s*, which forms a right angle with P Q. With the concentric dotted quadrants, carry the points in P *s* round to meet P *t* or P Q produced; and from the points therein draw lines parallel to the rake. Bisect C D in X, and square up the line X V. On X, as a centre, and with the radius X C or X D, describe the semicircle U V W, and draw C U, the line of the pier produced. From the points of intersection of the raking parallels with the semicircle, draw lines parallel to Q S, through the plan of the groin, and intersect these by lines drawn through the points of the body rib, parallel to the axis of the body range. Through the points of intersection trace the curved line *e f g h z n h g f e* Y, the seat of the groin.

To find the groin ribs.

Through the centre X, draw the line U W, parallel to the axis of the body range; and through E, where the line V Z drawn from the summit V cuts the raking line C D, draw E *r* parallel to U W. Through C, draw also C *o*, parallel to U W. Then on the plan join Y Z, Y Z, which are chords to the intersecting line; and draw other two lines parallel to them, touching the outside of the curve; and the distance between them will give the thickness of stuff required for the intersecting rib; and through the points of intersection of the parallels, that is, through the points on the seat of the groin *e f g h*, &c., corresponding to the points 1 2 3 4 5 on the body and side ribs, draw indefinite lines perpendicular to Y Z, Y Z. At Z, set up the height *n n*, corresponding to the height *o p* of the side rib, and join Y *n*: at Y set up the height *r* D of the side rib, and draw the raking line Z *m l*, &c. Then the heights on each side of the side rib *a* 1, *b* 2, *c* 3, *d* 4, and E V, set up on the lines below at *i* 1, *k* 2, *l* 3, *m* 4, Z A, will give the curve of the groin rib.

To describe a Welsh or under-pitch groin; a groin in which the side arches are lower than the arch of the body range.

PLATE VII. *Fig.* 1.—Let A B C (No. 1) be the body rib, and E F G the side rib; then to find the intersecting ribs, divide half the rib E F into any number of equal parts 1 2 3 F; and from these points let fall perpendiculars 1 *c*, 2 *d*, 3 *e*, F *f*, and produce them indefinitely. From the same points 1 2 3 draw lines parallel to G E, intersecting *l n*; transfer the divisions from *l n* to *l m*, by quadrants drawn from *l*; then from the divisions of *l m* draw lines parallel to A C, intersecting the body rib A B in the points 1 2 3 *a*. From these draw perpendiculars to A C, through *c d e f*, and produce them until they intersect the perpendiculars from the corresponding divisions of the side rib in *g h i* I. Then a curve traced through the intersections will be the place of the intersecting ribs upon the plan.

On the inside of the curve so found draw two chords H I, K I: draw two other lines parallel to these to touch the outside of the curve; and the distance between these lines will show the thickness of stuff required for the intersecting rib.

To find the ribs:—Through the intersecting points *g h i* I draw lines perpendicular to the chords, H I K I; and make the heights *c* 1, *d* 2, *e* 3, I L, measured from the chord line, equal to the corresponding heights *c* 1, *d* 2, *e* 3, *f* F, measured from the line E G to the curve of the side rib; and a curve drawn through H 1 2 3 L will be the mould for the intersecting rib.

To find the mould under the intersecting ribs, or the cover of the vault E H I K G:—On the line A B (No. 2)

GROINS.

Fig. 1. No. 2

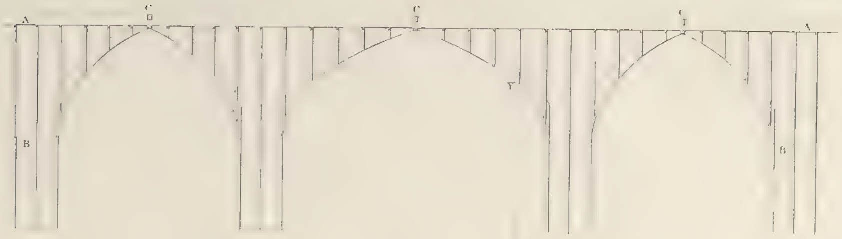


Fig. 1. No. 1

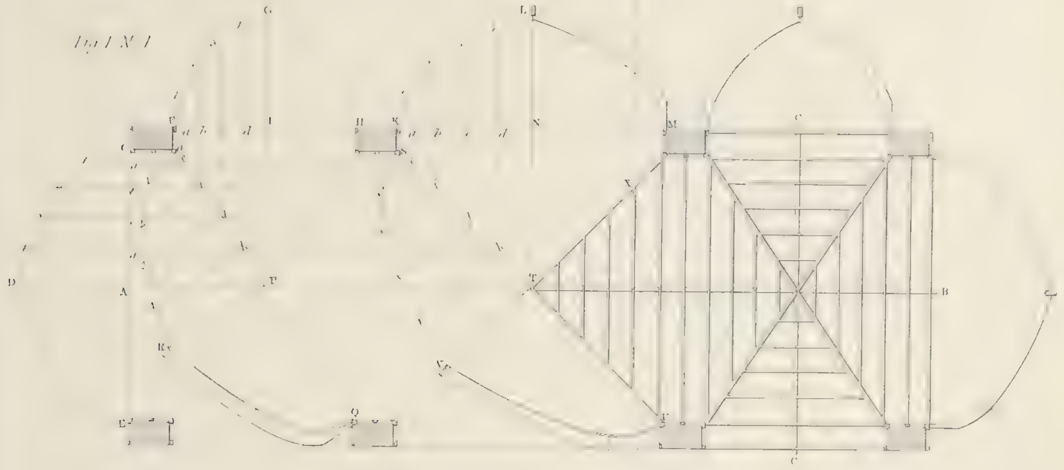
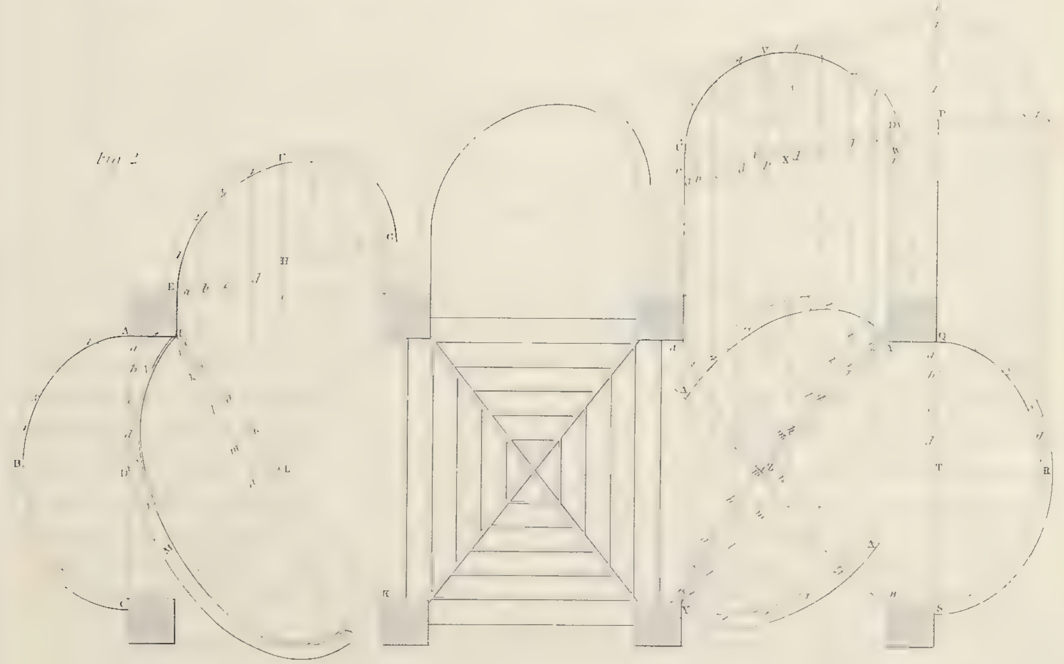
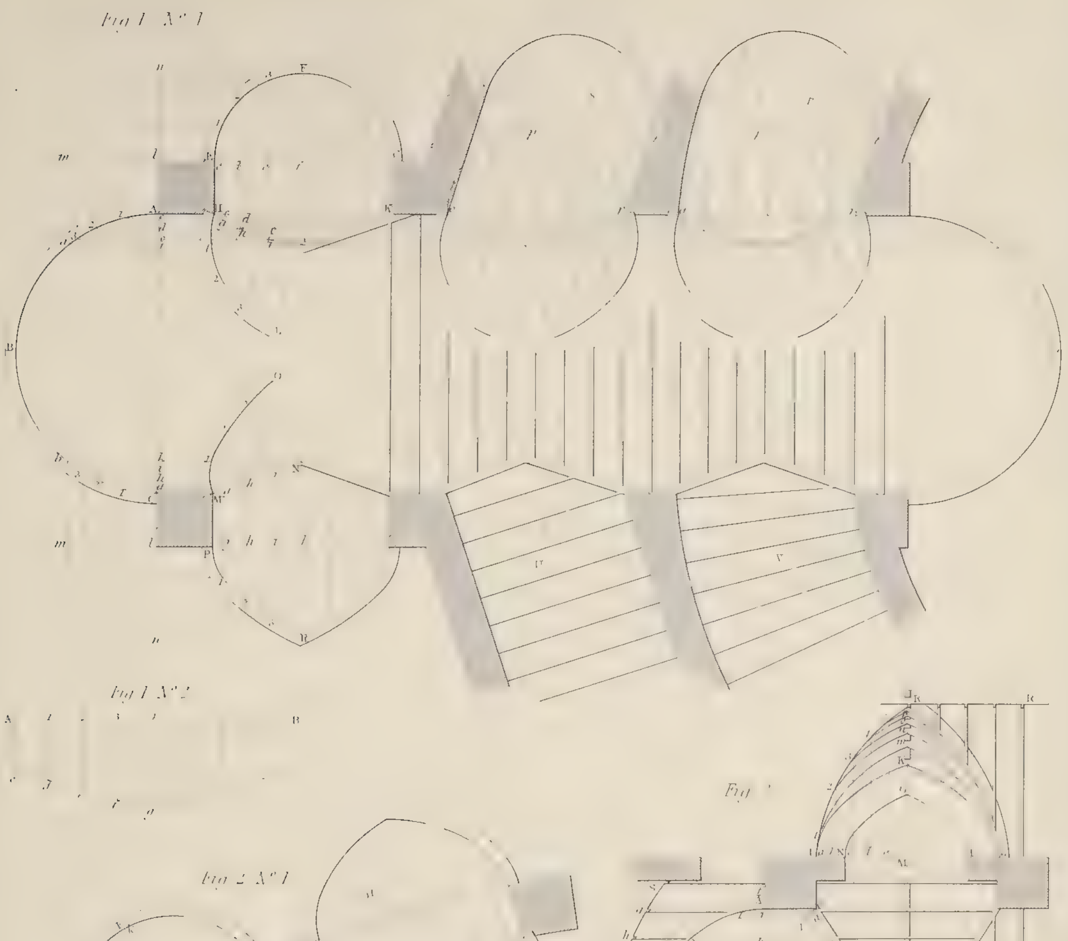


Fig. 2



GROINS.



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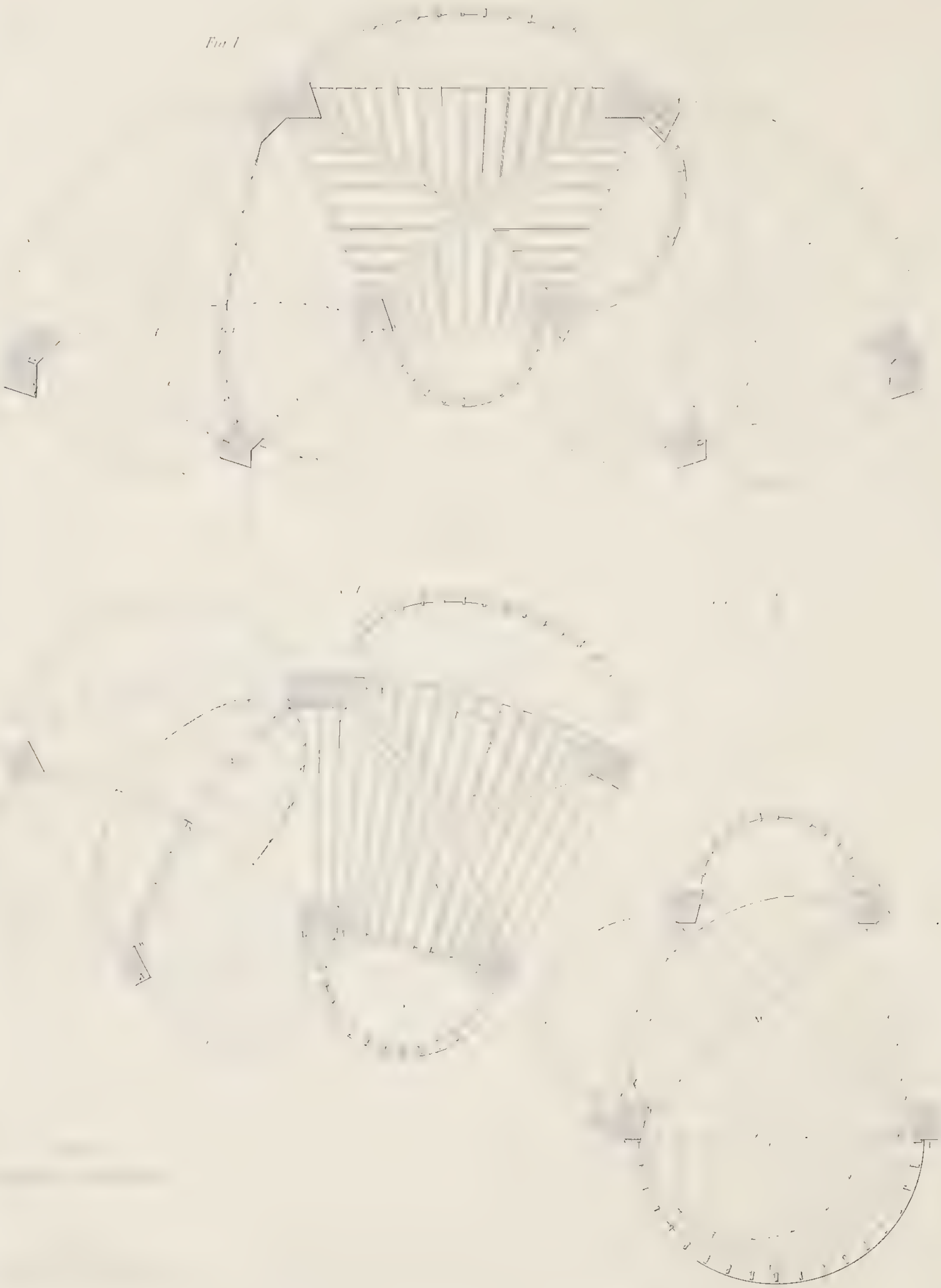
GROINS

Fig. 1



set off the divisions 1 2 3 4, corresponding to the divisions 1 2 3 F on the under side of the side rib E F G; and draw the perpendiculars A *c*, 1 *d*, 2 *e*, 3 *f*, 4 *g*, &c., and make them equal to E H, *c g*, *d h*, *e i*, *f* I; then a line drawn through *c d e f g* will be half the mould required.

The under side of the plan in the same figure shows a Gothic side arch. The method of proceeding is precisely the same as for the semicircular arch. The side arch P R is divided into equal parts in 1 2 3 R; these divisions are transferred to the body rib C B; and the intersections of the perpendiculars from the two arches in *g h i* N, gives the points through which the curve of the intersecting rib is drawn. The seat of the intersection may be made a straight line by reversing the operation: thus, draw the centre line of the side range R N, and intersect it by the line *b* N, from the body rib B C; then join M N, and draw upon it from the points of intersection of the divisions of the body rib, the perpendiculars *g* 1, *h* 2, *i* 3, N O: set up on these the heights corresponding to the same points in the body rib, to find the curve of the intersecting rib; and set up the same heights on the perpendiculars drawn on P *k*, for the curve of the side rib.

In the side vaults S and T, the curves of the side ribs are drawn at *o p r*, and divided into equal parts, from which ordinates are drawn to intersect the line *o r*; and through the points of intersection, lines drawn parallel to the sides of the vault, straight in the one case, and curved in the other, to meet the lines from the divisions of the body rib, give the place of the intersecting rib.

Groins on a circular plan.

The ribs are described in the same manner as above, the lines from the ordinates *a b c d* (*Fig.* 2) of the body range being portions of circles drawn from the same centre as the lines of the plan. The lower half of the plan shows the method of backing or bevelling the intersecting ribs: dotted perpendiculars, *i* 6, *k* 5, &c., are drawn from the intersection of the curved lines *a e*, *b f*, *c g*, &c. with the tangent of the curve of the intersecting line on the plan; and the heights of the corresponding ordinates being transferred to them, the curve 6 5 3 4 T drawn through the points thus obtained is the bevel of the rib. *Fig.* 2, No. 2, is the development of the covering of the vault L R N; and requires no description.

To draw a Gothic groin in which the transverse axis is a curve joining the summit of the side arch to the summit of the body range.

Let A B C (*Fig.* 3) be the body range, I K L the side arch, and S S the section on the axis H M: draw the diagonal E H G, and divide it into equal parts in *a b c d e* H; through these points draw perpendiculars to both axes, and produce them indefinitely. Then to find the spandrels, transfer the heights *a* 1, *b* 2 of the ordinates of the body range, to the corresponding ordinates on the line 1 L for the arch 1 R L; and to find the intersections of the ribs 1 *g*, 2 *h*, 3 1, &c., with the body rib A S, transfer the heights *a g*, *b h*, *c i*, *d k*, *e l* to the line M R in K *m n o p*; then 1 *k*, 2 *m*, 3 *n*, 4 *o*, 5 *p*, &c., will be the curve of the spandrel rib *i g*, 2 *h*, &c.

The diagonal or intersecting rib is found by transferring the heights of the ordinates of the body range to the ordinates *a* 1, *b* 2, *c* 3, &c., of the diagonal.

Groining on an octagonal plan.

PLATE VIII. *Fig.* 1.—In the left-hand compartment, the groin is regular; and the method of procedure will be understood from the descriptions already given. The chords of the arches are divided into the same number of equal parts, and the opposite corresponding divisions are joined by lines whose intersections give the seats of the intersecting ribs, which in this case are represented by curved lines. The thickness of stuff required for the intersecting rib is found as in the underpitch groin, by drawing the chords and tangents to the curved lines of the plans.

The centre compartment shows the manner of finding the jack-ribs.

The right-hand compartment shows the method of finding the curve of the rib of the body range and diagonal, when the plan of the intersecting ribs is a straight line in place of a curve. It will be fully understood by inspection.

Groining on a circular plan.

Fig. 2, No. 1.—The corresponding ordinates in this figure have the same letters and numbers attached, so that a mere inspection will suffice to show the method of finding the lines.

Fig. 2, No. 2—Shows the method of describing the mould for the under side of the intersecting rib K L; and No. 3, that for the rib L I: the manner of backing the intersecting rib is as before described.

N M O, No. 1, shows the manner of arranging the jack-ribs.

To find the angle ribs of a cono-cylindric groin.

Let A D B (*Fig.* 3) be the conic arch, D C E the axis of the cone, and E its apex: also let L K be the diameter of the cylindric arch, and *r* M *a* its axis. Draw the seat of the intersecting rib F M G; also the dotted line *m* G: divide the semicircle L 4 K into any number of equal parts 1 2 3 4, and draw the ordinates 1 *u*, 2 *t*, 3 *s*, 4 *r*. Then from the points of intersection of the ordinates with the line L K, draw the lines *u n m*, *t o l*, *s p k*, *r* M *a*, &c., parallel to the axis *r* M *a*. At the points where these intersect the seat of the diagonal rib, draw ordinates *n* 1, *o* 2, *p* 3, M 4, &c., equal to the ordinates of the side arch, which will give the curve required. Or from *m l k a*, and the remaining points of intersection in *m* G, let fall perpendiculars to A B, meeting it in *i h g b*, &c. From the point 4 in A B, as a centre, where the perpendicular let fall from the intersection of the axis of the side arch with the seat of the diagonal meets A B, and with a radius equal to *r* L or *r* K, describe a semicircle; and from C, where the axis of the conical vault meets A B, with the radii C *i*, C *h*, &c., describe arcs cutting the semicircle in *f e d c*, &c., which will give the places of the ordinates.

PLATE IX.—Let A B C (*Fig.* 1) be the profile of the side arch. Bisect A C in D, and draw D B and A *d* perpendicular to A C: join A B: divide the line A B into any number of equal parts, and from D draw lines through the points of division 1 2 3 4, cutting the profile of the arch in *e f g h*; and from B draw lines through these last points, meeting the line A *d* in *a b c d*.

Then to find the diagonal ribs L L L:—On K H, the seat of the centre rib, raise the perpendiculars K I H *d*: make K I equal to D B; and transfer the divisions A *a b c d* of the line A *d* on the side arch to the line H *d*. Join I H, and divide the line into the same number of equal parts as the line A B. From K draw the lines K 1, K 2, K 3, K 4, produced indefinitely. Join I *a*, I *b*, I *c*, I *d*: and through the intersections of the two series of radial lines

draw the curve of the rib H *e f g h* I. The side rib G F E is found in the same manner.

Fan-tracery vaulting with centre pendant.

In this species of vaulting (*Fig.* 2), all the main ribs have the same curvature, and form equal angles with each other at the springing.

The plan shows the arrangement of the ribs. Those radiating from the imposts are all of equal curvature and equal length, as at A B in the profile; and are bounded by the curbs C F, which are quadrants drawn from the imposts as centres. D D is the plan of the pendants, the ribs of which have all the same curvature, as shown at *b c* in the profile. The jack-ribs between the curb of the pendant and the curbs of the fan arches lie horizontally.

In *Fig.* 3 the fan ribs are of the same curvature, but are increased in length from the sides to the centre; and the ridge ribs are necessarily not horizontal, but rise from I and L to G on the plan, seen also in the profile *l g*.

Let A B C be the profile of the side rib; then on D G, the diagonal of the vault, set off D H equal to A C, and draw H E perpendicular to D G; make the curve of the rib D E the same as A B, and continue it to F, the length of the longest rib; then the height G F will be the apex of the ridge ribs. The length of the other ribs is found thus:—From the point D as a centre, draw arcs from *a c*, the intersection of the ribs with the axis I G, to meet D G as at *b d*; and draw *b e*, *d f* perpendicular to D G. Then D *e* will be the profile of the rib D *a*, and D *f* that of D *c*, and so on for the other ribs.

Groined vault on an octagonal plan, with an octagonal skylight.

Fig. 4.—The ribs of the octagonal groin are found by the method of intersection as in *Fig.* 1. The chord line A B of the side arch is divided into equal parts, and lines are drawn from C through these to meet the curve; through the points of intersection *d e f*, lines are drawn from B, and produced to meet the line A *c* in *a b c*. The chord lines D E, G I on the plan, are similarly divided into equal parts, and the divisions of the line A *c* are transferred to the perpendiculars D *c*, G *c*. The intersections of the lines drawn from F and H, with those drawn from E and I to the divisions in D *c*, G *c*, through these divisions, give the points *d e f*, *d e f* in the curves of the diagonals.

To find the ribs of a groined vault on an irregular octagonal plan, with a pendant in the centre.

PLATE X.—A B C D E F (*Fig.* 1, No. 1) is the semi-plan of the vault. Let C H D be the profile of the arch of one of the larger sides. To find *n r o*, the profile of one of the shorter sides: Bisect C D and *n o* in I and *q* respectively, and draw I H perpendicular to C D, and *q r* to *n o*; make *q r* equal to I H, join H D, *n r*, and draw the perpendiculars D *e*, *n i*, *o p*: divide the chord lines H D, *n r*, *o r*, into the same number of equal parts, and draw the intersecting lines, to find the curve of the smaller arch as before.

Proceed in the manner already described to find the profiles of the ribs M O, C S, C O, O O, D O, as shown by the diagrams *s u t*, &c.

The length and profile of the jack-ribs P P, R R, are found by drawing lines from their intersection with the ribs M O, K O, as shown on the left-hand side of the figure at M N K.

Fig. 1, No. 2, shows the mode of construction: A A is the girder supporting the floor above the groined ceiling; B B is the ridge of the ceiling, the seat of which is A G F in the plan No. 1; C C are the main ribs; *h h*, the diagonal rib corresponding to R R in the plan; *g g* are the ribs P P, and jack-ribs of the side arches; *f f* are the ribs of the pendant marked T T on the plan, all of equal length and curvature; C C, an iron bolt by which the pendant is supported; and *k k*, the curb marked *z y* O *t w* on the plan.

PENDENTIVES.

PLATES XI., XII.

If a hemisphere or any other portion of a sphere *a c b* (Fig. 348), be intersected by vertical planes *e d*, equi-distant from its centre, the angular portions *h h*, between the boundaries of the planes, are pendentives.

In like manner, in a conoid *a c b* (Fig. 349), the angular portions *f f f*, between the intersecting planes, *e d*, are

Fig. 348.

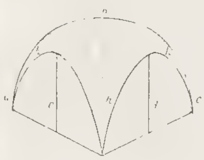
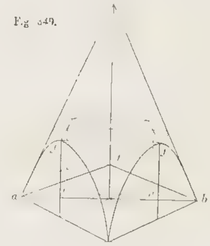
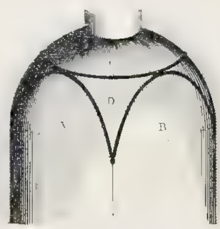


Fig. 349.



pendentives, and the same in an ellipsoid. In these figures, the convex surfaces of the hemisphere and conoid are shown, but in vaulting, it is of course the concave surfaces which form the pendentives, as in the following figure, where A and B (Fig. 350) are two of the contiguous intersecting planes; C, part of the concave surface of the vault; and D, one of the pendentives. It is scarcely necessary to remark, that the resulting curve of the intersection of a spherical vault by a plane, will be a portion of a circle, that of an ellipsoid will be an ellipse when the plane is parallel to the major axis, and that of a conoid a hyperbola.

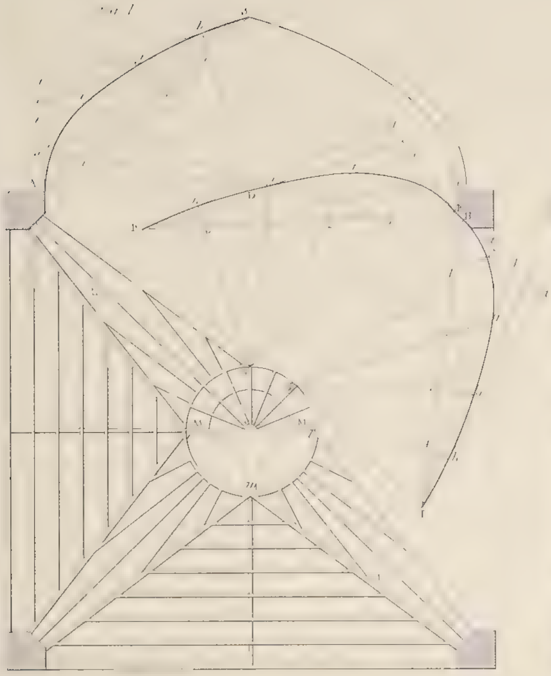
Fig. 360.

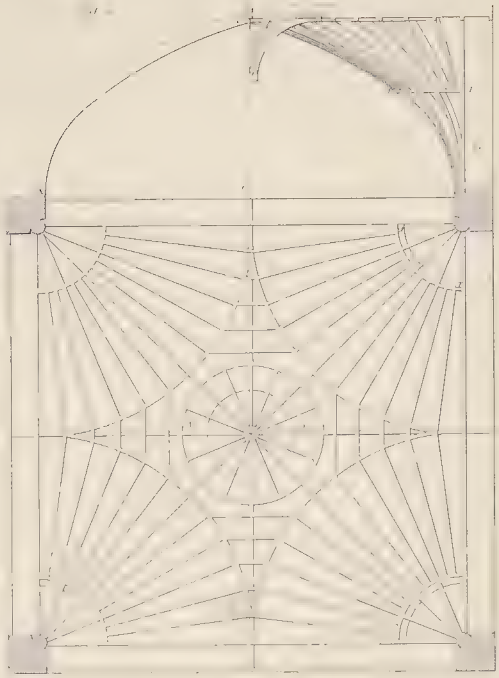


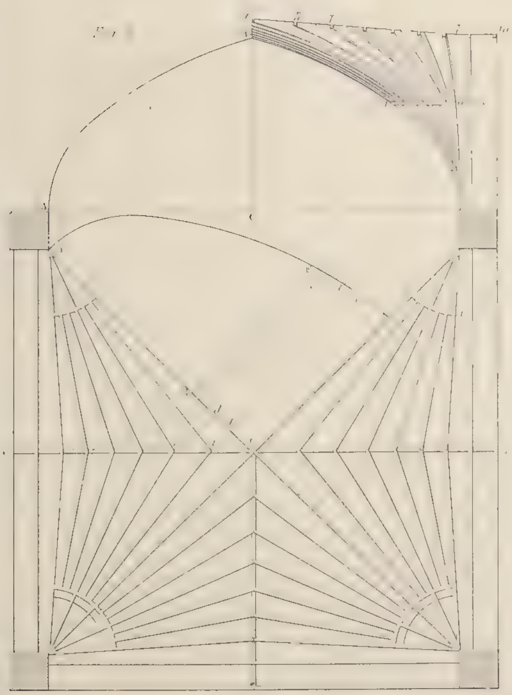
To cove the ceiling of a square room with spherical pendentives, having a circulr skylight in centre.

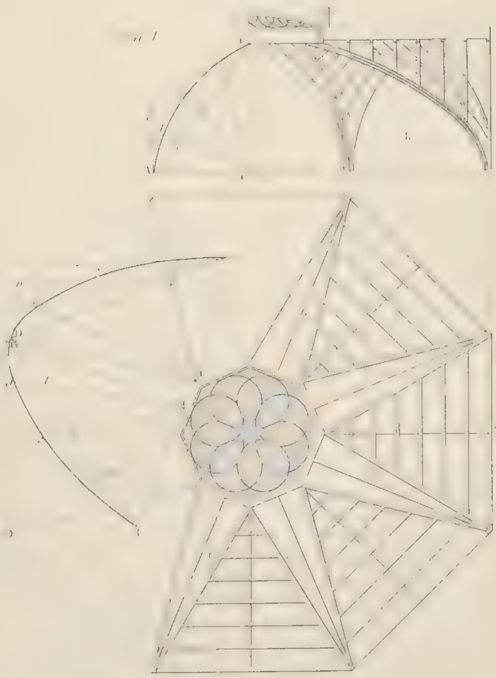
PLATE XI.—Let A B C D (*Fig.* 1, No. 1) be the plan of the room: draw the diagonals of the square, and from their intersection E describe the inscribing circle A B C D, which will be the plan of the hemispherical vault. On any of the sides of the square A B, B C, describe a semicircle which will be the curve resulting from the intersection of the hemisphere by the plane of the side of the square. To find the seat of the ribs: From the centre E describe a circle of the size required for the skylight, and draw the double line showing the breadth of the curb *b*. Divide the circle into as many equal parts as there are ribs required, and from the points of division draw radii for the centres of the ribs. Set off half the thickness of the rib

GROINS.





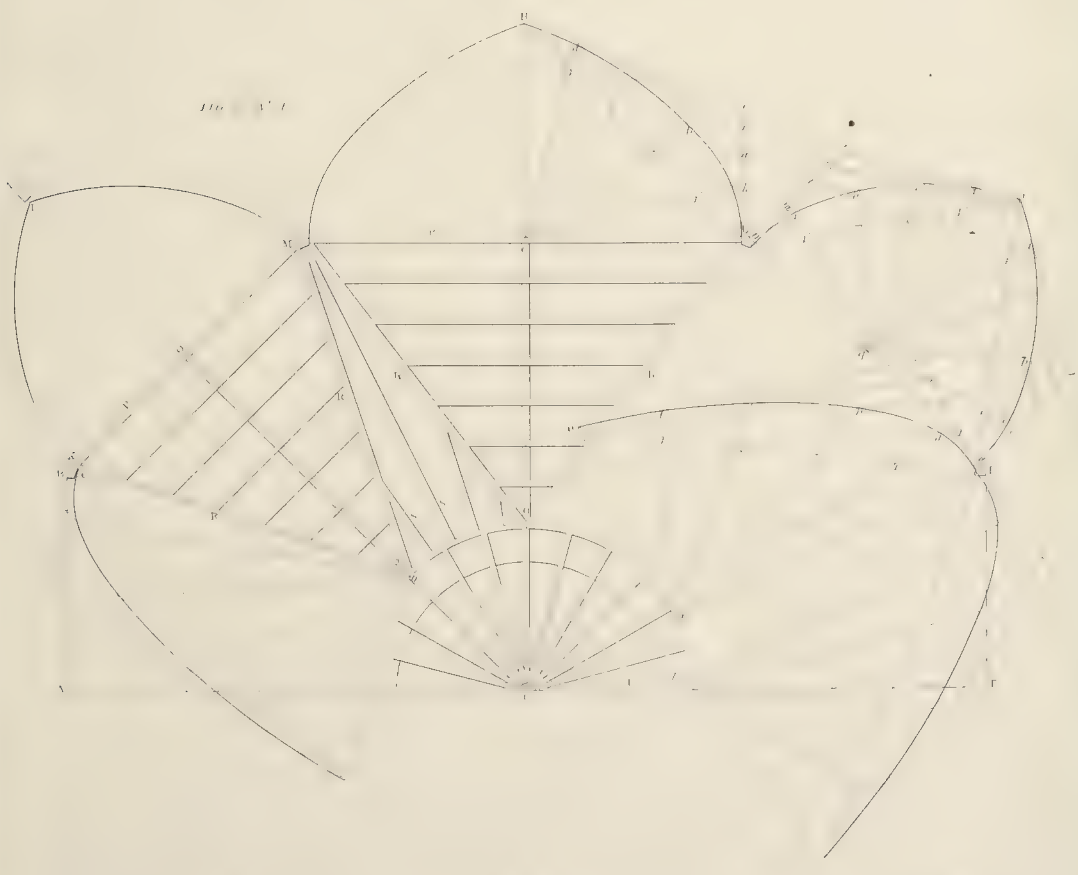




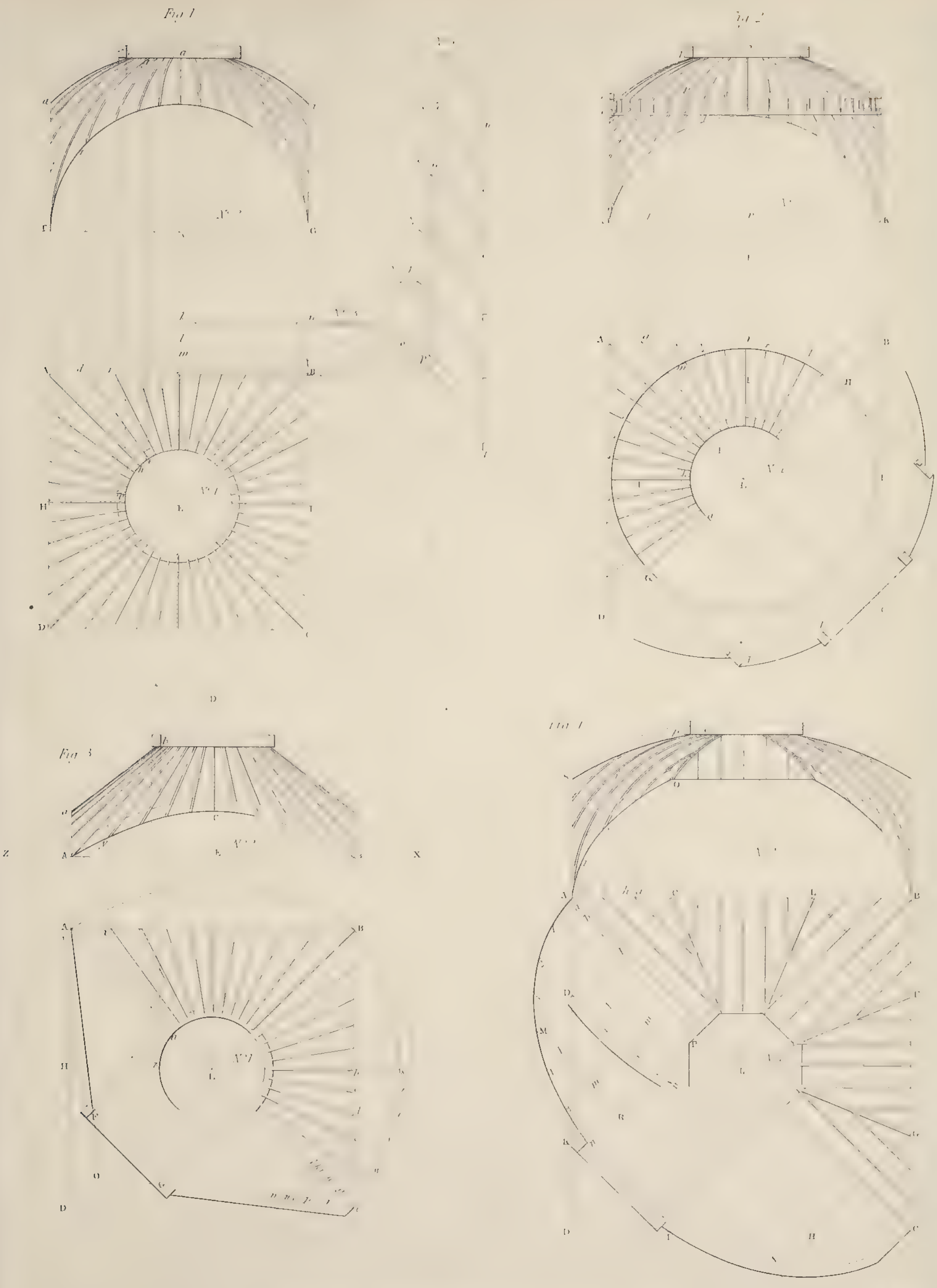
GROINS.

Fig. 1. N° 2

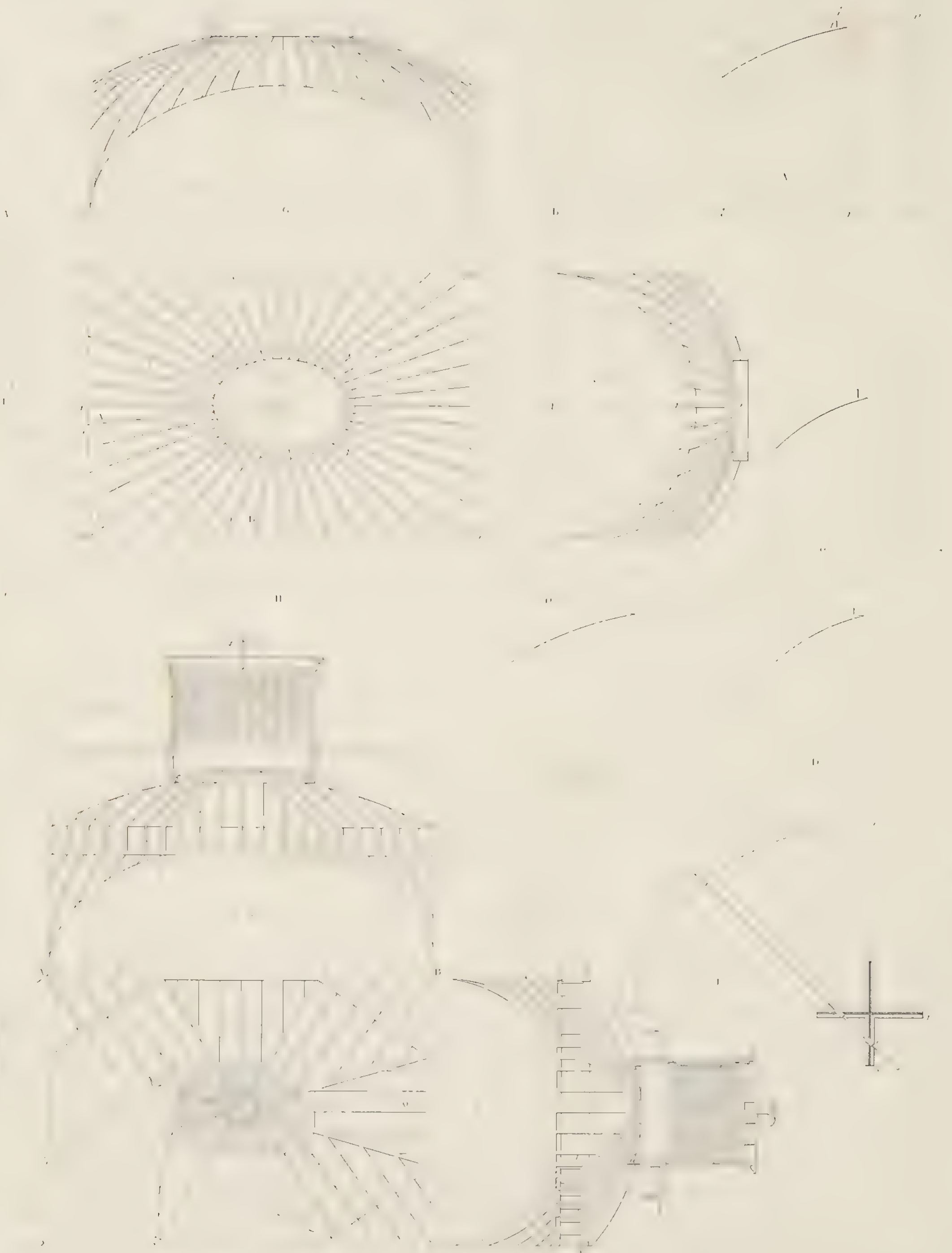
Fig. 1. N° 1



PENDENTIVES.



J. White del.



on each side of the radial lines, and draw parallel lines representing the sides of the rib. If the ceiling is to be finished with plaster, the ribs should be nowhere more than 12 inches apart.

No. 2 is a section on the line H I of the plan. Bisect the line F G in *s*, and draw the semicircle for the resulting line of the intersection of the hemisphere. From *s*, with the radius E A, describe the segment *a a a* representing the section of the spherical surface on the line H I; draw the curb *c* from the plan, as shown by the dotted lines; and find the intersection of the other ribs with the side arch and the curb, by drawing lines from the plan, as from *d* to *f* and from *e* to *g*. The projections of all the ribs except the central rib and side ribs *a a* will be elliptical curves.

To find the length of each rib.

From the centre E, with the radius E A, describe the arc A *k*, and draw *k n* parallel to the side of the plan. Then with the same radius, from I as a centre, describe the arc *n t* for the under side of the rib A *h*. From E describe the arcs *d l*, *r m*, &c., and draw *l o*, *m p*, to intersect *n t* in *o*, *p*; then *o t* and *p t* will be the lengths of the ribs *d e*, *r f* respectively. By drawing the lines *o* 4, *p* 5, and *t u*, and describing arcs with the same radius as *t n* or E A, all the ribs may be drawn separately, as Nos. 4, 5, 6, 7, 8. The double dotted curves A *k*, *d l*, *r m*, show how the bevel of the end of the ribs is obtained.

Fig. 2 is a spherical vault less than a semicircle, with a plain fascia introduced in the vault above the pendentive: the curve resulting from the intersecting planes is the segment of a circle.

A B C D is the plan of the room, E is the centre of the segment, G *m* H L is the plan of the double curb over the pendentives, and *k* the curb of the skylight. From the centre E on the line E A, make E F equal to *r* F, and from F describe the curves D *c*, *d b* of the ribs D G, G *a*. The dotted lines drawn from the plan show the manner of obtaining the section of the curbs *c d*, *b*.

In the section No. 2, make *r* F equal to *r* F in the plan, and F is the centre of the segment I K, *e l o*. The position of the ribs is found by drawing lines from the plan, as *g h*, *m p*.

Fig. 3, No. 1 and No. 2, are the plan and section of a conical pendentive: A B C D is the plan of the room, and the base of the cone is the inscribing circle A B C D, described from E, and shown by a dotted line.

To find the ribs:—Make E O, No. 1, equal to the height of the cone, and join A O, C O. From the plan of the curb draw the dotted lines intersecting A O and C O in F and G. From the centre E describe the arcs *b l*, *c k*, *d i*, *e h*, *f g*, meeting E C in *l k i h g*; and draw the perpendiculars *l m*, *k n*, *i o*, *h p*, *g r*, cutting the line C G. Then *m* G will be the length of the rib *b*, *n* G the length of *c*, and so on.

To find the hyperbola resulting from the intersection of the sides:—Make the perpendicular *b s* equal to *l m*, *c t* equal to *k n*, *d u* to *i o*, *e v* to *h p*, and *f w* to *g r*; then trace the curve through *s t u v w*.

In the section No. 2, produce A B to X and Z, and make E D equal to E O, the height of the cone; join Z D and X D. Find the hyperbola A C B, as in the plan, or transfer it by ordinates. Find also the intersections of the ribs with the curve A C B, by drawing lines from the plan, as *x y*; and find their intersections with the curb *b* in the same manner. Then from the intersection of the ribs with the line A C B, as at *y*, draw lines converging to D, for the vertical projection of the ribs.

Pendentive formed by the intersection of an octagonal domical vault by a square.

Let A B C D (*Fig.* 4, No. 1) be the plan of the square apartment, C E F G H I K D the plan of the octagonal vault, and A K I C the curve of one of the longest or diagonal ribs A C. Then to find any of the angle ribs, as D P:—Produce C D to M, and divide the portion M K of the rib A C into any number of equal parts, as 1 2; and through the points of division draw 1 *l*, 2 *m*, cutting the line D P in *l* and *m*. On D P erect the perpendiculars *l* 1, *m* 2, P *n*, and make them equal to the corresponding ordinates *l* 2, *m* 2, R *n*; and through D 1, 2 *n*, draw the curve of the rib.

The intermediate parallel ribs are all portions of the same curves, and their lengths and bevels are found by drawing lines *e* 1, *f* 2, *g* 3, &c., from the intersections of the lines of the ribs with the side of the square to the points 1 2 3, &c., of the rib A C.

To find the projections of the ribs in the section No. 2:—From the points *e f g* C in the plan, draw the perpendiculars *e* 1, *f* 2, *g* 3, C C, and transfer to them the heights of the perpendiculars *a* 1, *b* 2, *c* 3, *d* M, as shown by the dotted lines *d i*, &c., which will give the points 1 2 3 O, through which the curve of the wall rib A O is to be drawn, and the same points also give the intersections of the jack-ribs with the wall rib.

PLATE XII.—*To draw an elliptical domical pendentive roof.*

Let *h k l m* (*Fig.* 1, No. 1) be the plan of the apartment: draw the diagonals *h l*, *k m*, and through *c* the lines E F, G H, parallel to the sides of the apartment. To find the circumscribing elliptical base of the dome:—From the centre *c* describe the quadrant *u* 2 3, and bisect it at 2; and through 2 draw 1 2 *t* parallel to the side of the rectangle *h k*; join *t u*, *t v*. Then from *h* draw *h* E, *h* G parallel to *t v*, *t u*, respectively, cutting the lines E F, G H in E and G; and complete the parallelogram A B D C, which will be the circumscribing rectangle of the ellipse forming the base of the dome. The ellipse of the curb is proportioned by drawing *a b c d* to meet the diagonals of the rectangle *h k l m*.

On the line B D (No. 3) describe the semicircle B *r* D, as the section of the dome on its minor axis. Then, as the dome may be considered a solid, formed by the revolution of the semi-ellipse E G F round its axis E F, it follows that all sections of it by planes parallel to G H will be circles. Therefore, to find the wall rib *k l* on B D, from the centre F, and with the radius *c u*, describe the semicircle *n p o*. For the same reason, all sections made by planes parallel to E F will be similar figures. Hence *n p o* (No. 2), the wall curbs for the sides *h k*, *m l*, will be the circumscribing ellipse of *v t u* on the plan.

The other ribs may be found by the method of ordinates; but they are much more accurately and easily drawn by the trammel, in the manner shown at E. The points *g h i k* of the trammel being set on the major and minor axes of the ellipse, and *d e* being made equal to the minor, and *d f* to the major semi-axis, the distance between *d* and *e* will necessarily remain constant in describing all the figures A B C D E, but *f* will be moved nearer to

e for the curve of each rib in every quadrant. *Fig.* A shows the manner of finding the length of the rib marked *a d g* on the plan. The line *a c* (*Fig.* A) is made equal to *a c* on the plan; and the lengths *a d* and *g c* correspond to the lengths similarly marked on the plan, showing the intersections of the rib with the wall, and with the curb. Perpendiculars *d e h* and *g f*, drawn from *d* and *g*, give the proper lengths of the rib on the curve. The lengths of the ribs B C D E are found in the same way, as shown by the figures B, C, D, and E.

A domical pendentive of an irregular octagonal plan over an apartment, the plan of which is a parallelogram.

A B C D (*Fig.* 2, No. 1) is the plan of the apartment: the mode of proportioning the ellipse of the base of the dome, and the octagons of the curbs, is the same as in the last figure. In No. 2 the elliptic curves of the centre rib on the line of the major axis, and also the wall rib on the side A B, are shown. No. 3 is the section across the centre of the plan. The method of finding the other ribs will be found by inspection, as all the corresponding parts are similarly lettered and numbered.

DOMES.

Plates XIII., XIV., XV.

The word *dome*, derived from the Latin *domus*, a house, is employed among the moderns to signify the exterior form of a vaulted roof springing from a polygonal, circular, or elliptic plan. Domes are frequently used to cover vaults, the concave ceilings of which are termed cupolas, from their resemblance to an inverted cup. Sometimes the dome, or exterior surface, coincides in form with the cupola which it covers, but in constructions in carpentry the dome frequently does not indicate the internal form of the vault.

Domes in carpentry are composed of a certain number of ribs, placed vertically in planes, which, in spherical domes would, if prolonged, pass through the vertical axis of the dome. When the surface of the dome is a surface of revolution, all the ribs have the same exterior contour or profile. In domes on polygonal plans, the angle ribs at the intersections of the sides of the solid, alone, are in planes which pass through the axis. The ribs generally spring from a wall-plate or curb, forming a ring laid on the walls which support the dome, and this ring should be made sufficiently strong to resist the lateral thrust of the ribs, so that the walls may have to support the downward pressure or weight of the dome only.

The central point in the curved surface of a dome is called its pole or centre; the imaginary straight line drawn from the pole to the base, is its axis. When the height of a dome is greater than the radius of its base, it is said to be surmounted; when less, surbased. When there is an aperture at the pole of a dome, it is called its eye.

An oblong surbased dome on a rectangular plan.

Plate XIII.—The plan, *Fig.* 1, No. 1, shows the mode of placing the ribs. No. 2 is the section across the shortest diameter of the plan; and No. 3, the section on the line of its longest diameter. The curve of the rib E *n e n* F, and of all the ribs parallel to it, is found by dividing the segment C *n e n* D, No. 2, into a number of equal parts, and drawing lines from the divisions to meet the diagonal A B, No. 1, in the points *f g h i*, and from those points drawing lines parallel to C D, cutting E F, and produced indefinitely; then transferring the heights of the ordinates on C D, *a* 1, *b* 2, C 3, &c., to the corresponding ordinates on E F.

The curve of the diagonal ribs A *k* B is also found in the manner above described, as the lines show. The positions of the purlins *n m n*, and their projections on the plan, are found by drawing lines from their sections at *n e n* to meet the diagonal.

A surbased dome on an octagonal plan.

In *Fig.* 2, No. 1, the position of the ribs is shown, and also the manner of finding the curve of the angle ribs. No. 2 is a section on the line A B. On the plan No. 1, the rib standing over C G is drawn at G 1 2 3 4, *c*, and divided into equal parts, from which ordinates are drawn to the chord line, and produced to the line of the angle rib H I; from the points *h i k l*, in which these intersect H I, the seat of the angle rib, ordinates are drawn; and the heights F *c*, *d* 4, *e* 3, &c., being transferred to them, give points through which the curve of the angle rib is to be traced.

Fig. 3, Nos. 1 and 2, are the plan and section of a hemispherical dome; and *Fig.* 4, Nos. 1 and 2, are the plan and section of a dome which is the half of a prolate spheroid on a circular plan. The corresponding parts in these plans and sections are connected by dotted lines; and the construction is so obvious that no description is required.

Manner of dividing conical, spherical, and other vaults, into compartments and caissons.

Plate XIV.—Let No. 1, *Fig.* 1, represent part of the plafond of a conical vault, and No. 2 part of a vertical section through its axis. Having divided the plafond into the number of panels and ribs or fields between them that is suitable to the design, the heights of the caissons and of the horizontal fields between them are found as follows:—On A *e*, No. 1, draw the circle *b b*, making it a tangent to the generating circle of the vault, and to the lines A *b*, A *b*; and through its centre draw *b* F perpendicular to A *e* Draw also the circle *a a* tangential to the lines A *a*, A *a*, the width between which is equal to the width of the ribs or fields between the panels. Produce the side of the cone C D, No. 2, to cut the perpendicular *b* F in *e*, and from *e* as a centre describe two circles, *c d*, *f g*, equal to the circles *b b*, *a a*, No. 1; and through the centre *e* draw the line *e* B perpendicular to the side of the cone C D, and cutting the axis C E produced in B: draw also B *c*, B *f*, B *g*, B *d*. Then, to find the height of the first field: In the section No. 2, through the point D draw a line *o* D *l* parallel to B *g*, cutting the produced axis in *o*; and with the centre F, on the line *b* F′, describe the circle *k l* equal to *f g*; and draw *k o*, cutting the side of the cone in *h*, which is the height of the first field. Through the point *h* last found, draw the line *n h o* parallel to B *d*, and from the centre G, on the line *b* F′, describe the circle *m n* equal to *b b*, and having *n o* for its tangent; and join *m o*: the point where this line cuts the side of the cone is the height of the first caisson. Proceed in the same manner with the circles F′, G′, &c.

Manner of dividing a Gothic vault into compartments.

Fig. 2, No. 1, is a portion of the plan of the vault; the point *c* is on the line of the axis produced; *a a* is

DOMES.

Fig. 1

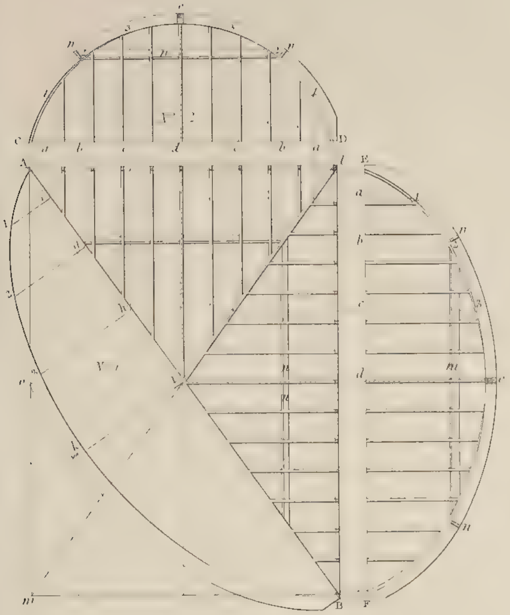


Fig. 2

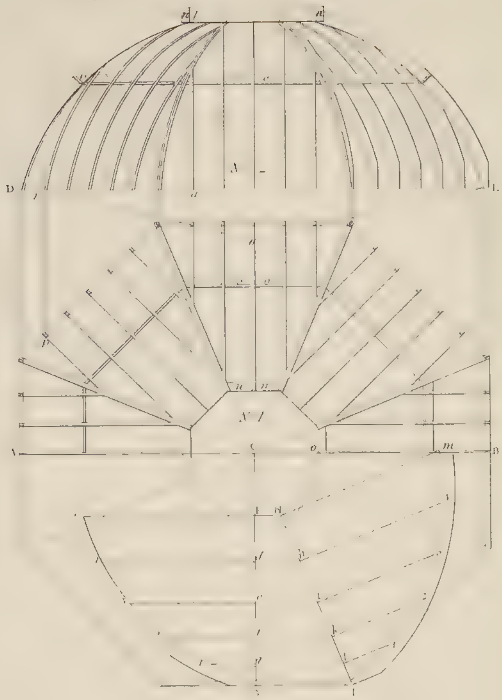


Fig. 3

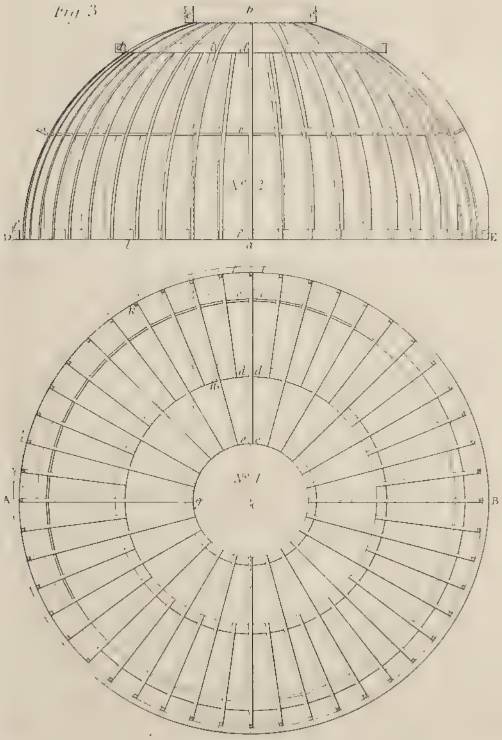
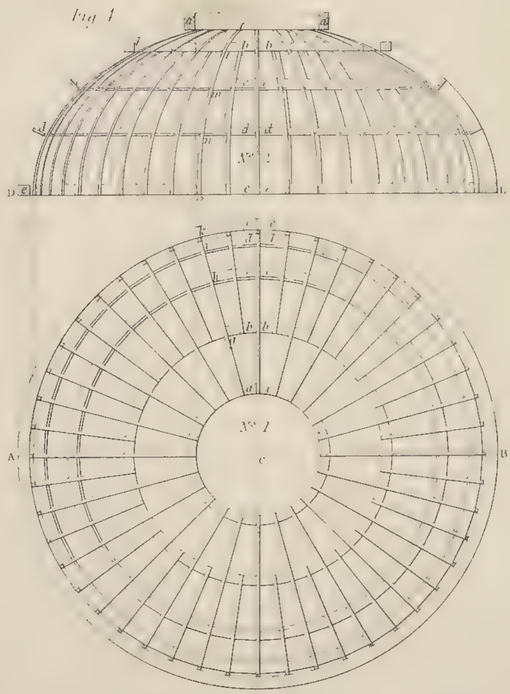


Fig. 4



J. White del.

J. W. Lowry sc.

12 6 0 1 2 3 4 5 6 7 8 9 10 20 Feet

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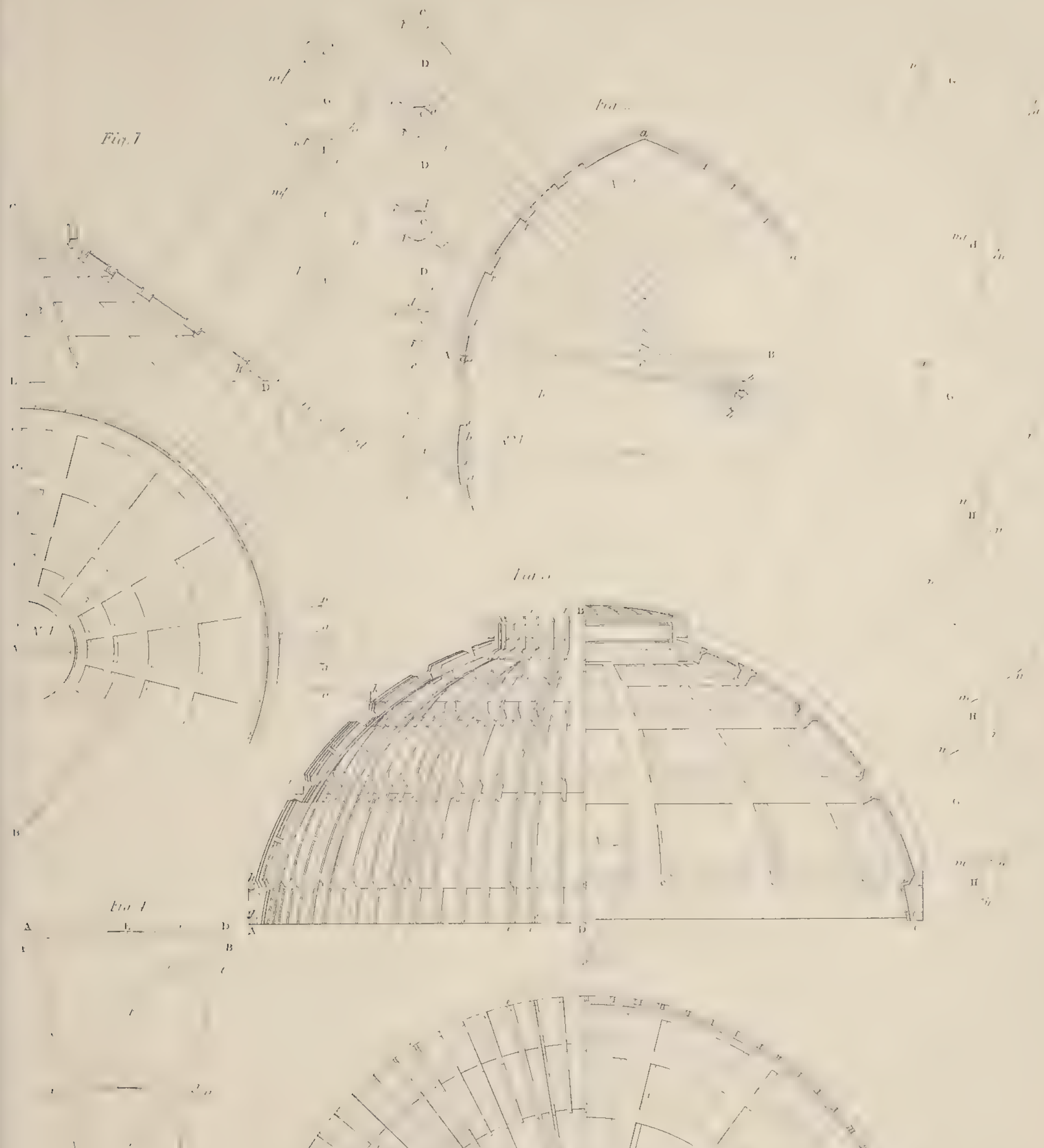
DOMES.

PLATE XIV



J White del.

J.W. Lowry fc

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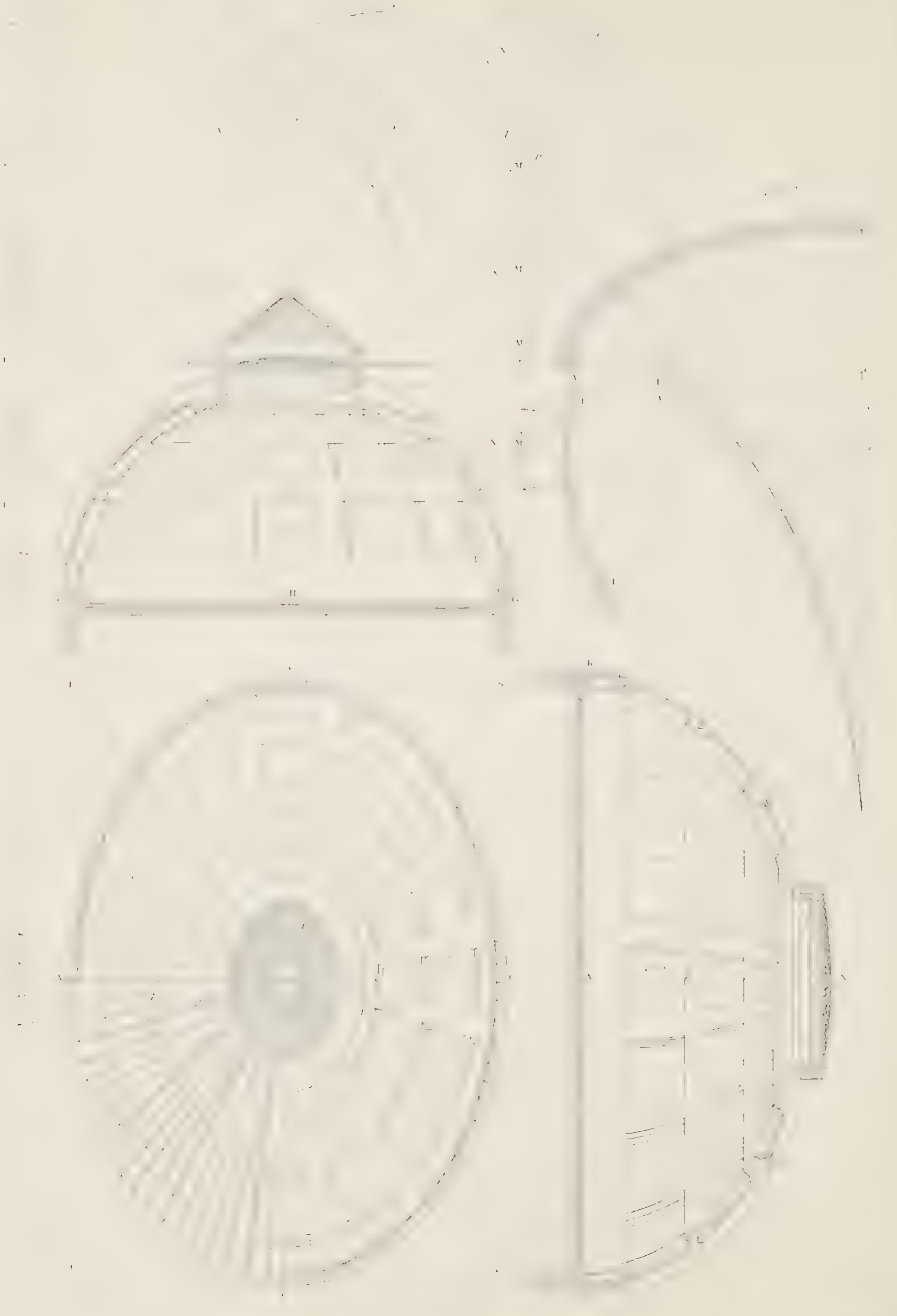


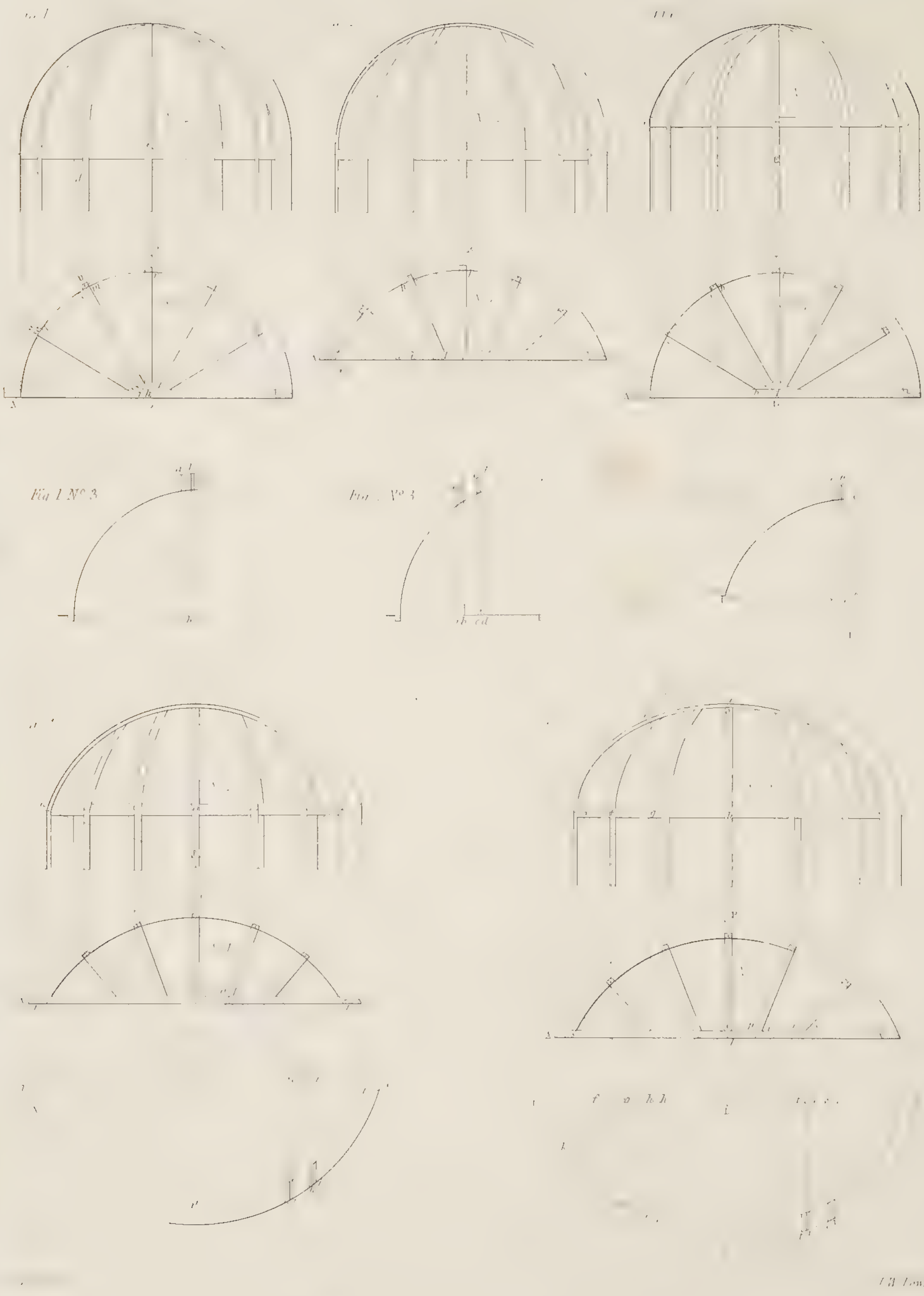


Fig. 1 Nº 3

the width of the panel, and *b b* the width of the field between the panels. From the centre *d*, the circles *e e*, *f f* are drawn, touching the lines *c a*, *c b*, *c b*, *c a*, produced; and on the line drawn through *d*, perpendicular to *d c*, the centres of the other circles are found.

Having determined the commencement of the divisions, as at C, describe from that point, as a centre, the circle *a d* equal to the circle *f f*, in No. 1; and through C draw a line, *c b*, to the centre of the arc forming the side of the vault, and cutting the axis in *c*. Then, through *c* draw from the circumference of the circle *a d* the tangents *c a*, *c d*, and also produce them beyond the centre *b*; and between them, from *b*, as a centre, describe the little circle *g g*. Through the point *f*, where *d c b* cuts the arc of the vault, and which gives the height of the first field, draw *g f e*; and from D, as a centre, describe the circle *e e*, equal to *e e* in No. 1, and touching the line *g f e*; and through its centre draw D *b* to the centre of the arc of the vault, cutting the axis in *c*. Through *c* draw the tangents *e c*, *e c*, and produce them to beyond *b*; and from *b*, as a centre, describe the circle *h h* between them. It will be seen, by inspection of the figure, how the tangents determine the position of the circles D D′ D″, C C′ C″ on the perpendiculars *d* C‴; and how, by their intersections with the profile of the vault, the heights of the divisions are obtained.

To determine the heights of the divisions of a spherical vault.

Fig. 3, No. 1, is part of the plafond of a spherical vault, one-half showing the divisions, and the other the mode of framing. To find the height of the divisions:—Produce the meridian lines *d b*, *d b*, representing the width of the panels, and draw the circle *b c b*, touching the generating circle in G, and the lines in *b b*; draw also the meridians *d c*, *d c*, representing the width of the field between the panels, and describe the circle H. Through the centre of the circles, *a*, draw *a b* indefinitely, and perpendicular to *d a*. Then having fixed the first horizontal division on the profile of the vault, No. 2, draw through it the line E *m n*, and draw the circle H, touching it in *m*, and the larger circle G, touching the lesser one in *n*; H and G being respectively equal to the lesser and greater circle in No. 1. Then draw the second line E *m n* tangential to the circle G, and describe the circle H′, touching this line in *n*; and so proceed, drawing the tangents and the circles H and G alternately; and the intersections of the tangents with the profile of the vault determines the heights of the divisions.

To determine the horizontal divisions of the radial panels of a cylindrical vault.

Trace the angle A C D (*Fig.* 4) representing one of the vertical divisions of panels, and by means of the arc *c d* and the arcs intersecting at *e*, draw D *f* bisecting the angle A D C: *f* is the centre of the circle, which gives the size of the first division. Through the points of intersection of the circumference of the circle, with the centre line E C, draw *a g* parallel to A D; bisect *a g* C, as before, to find *f*, the centre of the second circle, and so on. Or, from C describe the arc F B, and draw B *f*; then describe the arc *a b*, and draw *b f* parallel to B *f*; the centres *f* being found equally well by either method.

To determine the caissons of an ellipsoidal vault.

PLATE XV. *Fig.* 1, No. 1, is a portion of the plan, and No. 2 is the profile of an ellipsoidal vault. The circles M M have their centres on the vertical line as before, and their diameters are determined by the angles made between the meridians *c* D, *c* D, *b* D, *b* D, indicating the divisions of the plafond. The points *f f*, *f f*, on the profile, are determined by the intersections of the tangents to these circles, which are also tangents to the curves G L, H L, K L. The first of these, G L, is determined in the manner we shall presently describe; the third, K L, is such as to coincide with all the tangents that can be drawn from the lower circumference of the larger circle, in all its positions on the vertical line; and the second, H L, coincides with all the lower tangents of the smaller curve.

To describe the curve G L:—On the major axis of the ellipse A D C (*Fig.* 2), let *a* and *b* be the foci; divide the profile A B into any number of equal parts in the lines 1 2 3 4 5, and join *a* 5, *b* 5, *a* 4, *b* 4, &c.; then bisect the angle *a* 5 *b* in *c*, by the line 5 *c h*, cutting the minor axis produced in *h*; and in the same manner bisect all the angles formed by the lines from the foci, meeting in the divisions 1 2 3 4, &c.; and draw lines through *d e f g*, cutting the minor axis in *k l m n*, then draw the curve *o h*, coinciding with their intersections.

In *Fig.* 3, No. 1 is the plan of a dome, No. 2 its transverse, and No. 3 its longitudinal vertical section. The position of the circles O P O′ P′ O″ P″ O‴, on the vertical line, are found as in the former case, and the divisions on the transverse profile of the dome are obtained by the intersection of the tangents. Then, to find the divisions on the longitudinal section, draw the circumscribing parallelogram R S U T, No. 1, and the diagonals R U, S T. Draw the divisions from the profile No. 2 to the transverse axis A C, No. 1, cutting the diagonals in *l m n o p r s t*, and through these points draw lines parallel to A C, and the points wherein these intersect the major axis B D, give the divisions on the longitudinal profile, *Fig.* 3.

NICHES.

PLATES XVI., XVII., XVIII.

PLATE XVI. *Fig.* 1, Nos. 1 and 2.—*Spherical niche on a semicircular plan.*

The construction of this is precisely like that of a spherical dome. The ribs stand in planes, which would pass through the axis if produced. They are all of similar curvature. No. 2 shows an elevation of the niche, with the manner of finding the projections of the ribs from the plan. No. 3 shows the bevelling of the back ribs, *a b*, against the front rib, at *f g h* on the plan; *a b* is the bevel of *a*, and *b c* of *b*.

Fig. 2.—*A spherical niche on a segmental plan.*

No. 1 is the plan. The dotted lines at *f g*, *h i* show the manner of finding the representation of the ribs in the elevation: *a b* and *c d* are the bevels of the back ribs, where they abut on the front rib. In No. 3, the quadrant F G is drawn with the same radius as the plan of the niche D A, and the lengths and bevels of the back ribs are found by taking the distances *f a*, *g b*, from the plan, and setting them on the line F H.

Fig. 3.—*A niche, the plan of which is a semicircle, and its elevation a circular segment.*

The plan No. 1, and elevation No. 2, will be understood on inspection. No. 3 shows the manner of drawing the

back ribs. With the radius H F equal to D A, No. 1, or E a, No. 2, describe the segment F G. Draw H G, and make G k equal to the height of the segmental head of the niche; and draw k F at right angles to G H. Then F c will be the centre back rib $i\ d$; and the lengths and bevels of the others will be found in the same manner as before.

Fig. 4.—*A niche, of which both the plan and elevation are segments of a circle.*

No. 2 is the elevation of the niche, being the segment of a circle whose centre is at E. No. 1, A B C, is the plan, which is a segment of a circle whose centre is D. It may be made of any depth: the manner of finding the ribs is the same. Having drawn on the plan as many ribs as are required, radiating to the centre D, and cutting the plan of the front rib in a, $b\ c$, $d\ e$; then through the centre D draw the line G H parallel to A C; and from D describe the curves $m\ l$, A G, C H, cutting the line G H; and make D F equal to E O, No. 2. Then from F as a centre, describe the curves $l\ l$ and G I H, for the depth of the ribs; and this is the true curve for all the back ribs.

To find the lengths and bevel of the ribs:—From the centre D describe the quadrant and arcs $a\ f\ b\ g$, $d\ h$, &c., and draw $f\ f$, $g\ g$, $h\ h$ perpendicular to D H, cutting the curve $l\ l$, and the lines of intersection will give the lengths and bevels of the several ribs.

Fig. 5.—*A niche whose plan is the segment of a circle and its elevation a semi-ellipse.*

Let D in the plan (No. 1) be the centre of the segment. Through D draw E F parallel to A C, and continue the curve of the segment to E F. Then to find the curve of the back ribs:—From $k\ l\ m\ n$, any points in the curve of the front rib (No. 2), let fall perpendiculars to the line A B, cutting it in $a\ b\ c\ d$. Then from D as a centre, describe the curves $a\ e$, $b\ f$, $c\ g$, $e\ h$, $d\ h$, and from the points where they meet the line E F, draw the perpendiculars $e\ k$, $f\ l$, $g\ m$, $h\ n$, $h\ o$, and set up on $e\ k$ the height $e\ k$ of the elevation, and the corresponding heights on the other ordinates, when E $k\ l\ m\ n\ o$ will be points, through which the curve of the back rib may be traced. The manner of finding the lengths and bevels of the ribs is shown on the other side of the figure, and does not require description.

To draw the ribs of a niche elliptic in plan and elevation.

PLATE XVII.—*Fig.* 1: Let No. 1 be the plan, and No. 2 the elevation of the niche. The ribs being all portions of ellipses, may be drawn by the trammel $d\ f\ e\ g$, as shown at No. 4. The rib c, in the elevation, is seen at a D in the plan No. 1. The bevel of the end $h\ i$ is seen at A a in No. 3, and that of the end $e\ f$ at $b\ c$. It is not necessary to describe it more minutely.

To draw the ribs of a niche elliptic in plan and elevation, when the ribs are at right angles to the curve at their points of junction.

Fig. 2: Let A B C (No. 1) be the plan of the niche, and No. 2 its elevation. Set off the places of the ribs on A B C. From B as a centre, with any sufficient radius, describe a circular segment H I; join H s, I s, H t, I t. Bisect the angles H s I, H t I, by the lines $s\ u$ E, $t\ v$ F, meeting the centre line B D of the niche produced in E and F.

Complete the parallelogram A G B D, and draw its diagonal G D. In B D take any points $o\ p\ r$, and through them draw the lines $o\ l$, $p\ m$, $r\ n$, parallel to D A, and meeting G D. Draw then $l\ g$, $m\ h$, $n\ i$ parallel to G A; and in the parallelograms thus formed, draw the elliptic quadrants shown by the dotted lines, all parallel to the original curve A B. The intersections of these curves with the seats of the ribs will give points on which the heights of the front rib at a 1, b 2, c 3, d 4, $e\ f$, are to be set up, as shown in Nos. 3, 4, and 5.

To draw the ribs of an octagonal niche.

Fig. 3: Let No. 1 be the plan, and No. 2 the elevation of the niche. It is obvious that the curve of the centre rib H G will be the same as that of either half of the front rib A G, F G. In No. 3, therefore, draw A B C D E, the half plan of the niche, equal to A B C H G, No 1, and make D G E equal to half the front rib. Divide D G into any number of equal parts 1 2 3 4, &c.; and through the points of division draw lines parallel to A G, meeting the seat of the centre of the angle rib C E in $i\ k\ l\ m\ n\ o$. On these points raise indefinite perpendiculars, and set up on them the heights a 1 in i 1, b 2 in k 2, and so on. The shaded parts show the bevel at the meeting of the ribs at G in No. 1.

To draw the ribs of an irregular octagonal niche.

Fig. 4: Let No. 1 be the plan, and No. 2 the elevation of the niche. Draw the outline of the plan of the niche at A B C D E F (No. 3), and draw the centre lines of the seats of the ribs B G, H I, C G, K G, D G, E G; draw also G L F equal to the half of the front rib, as given in the elevation No. 2, and divide it into any number of equal parts 1 2 3 4. Through the points of division draw d 1, c 2, b 3, a 4, perpendicular to G F, and produced to the seat of the first angle rib G E. Through the points of intersection draw lines parallel to the side E D of the niche, meeting the second angle rib D G; through the points of intersection, again, draw parallels to D C, and so on. The curve of the centre rib is found by setting up from $n\ o\ p\ q$ G the heights d 1, c 2, &c., of G F, on the parallel lines which are perpendicular to K G. The curve of the rib B G or E G is found by drawing through the points of intersection of the parallels, perpendiculars to the seat of the rib, and setting up on them, as at $h\ m\ r$ I G, the heights d 1, c 2, &c. No. 4 shows the rib C G, and No. 5 the intermediate rib H I.

The plan of a semicircular niche in a concave circular wall being given, to find the ribs.

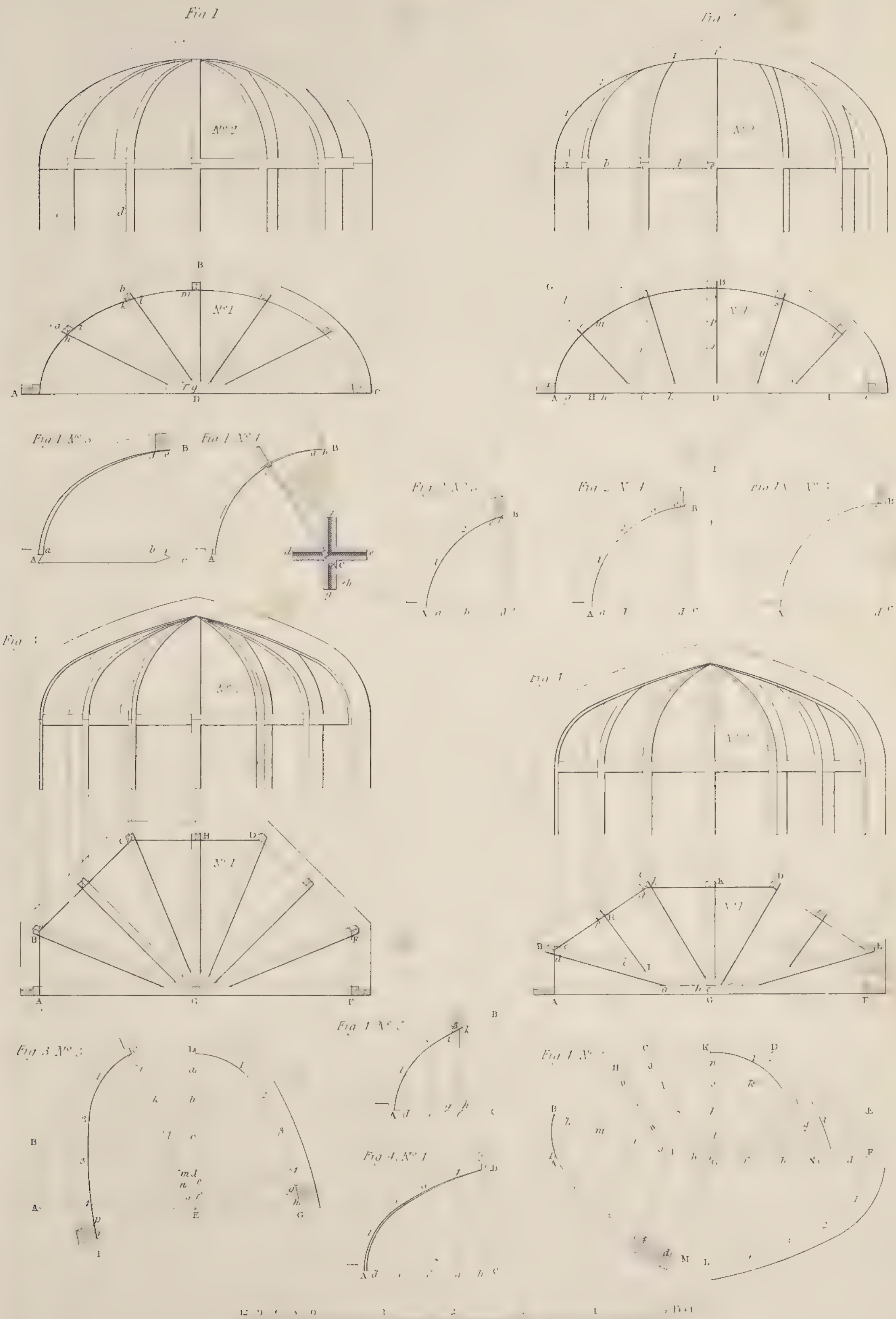
PLATE XVIII.—*Fig.* 1: Let A B C (No. 1) be the plan of the niche, and A p C the line of the wall. Join A C, and bisect it at D; and draw the plan of the ribs, $l\ s$, $n\ u$, $p\ h$, &c., and their elevation, as in No. 2, finding their intersections on the plan at $r\ s$, $t\ u$, h, $l\ m$, $n\ o$, p.

The ribs being in this case segments of a sphere, will all have the same curvature; and their lengths will be obtained by describing the quadrant A B C (No. 3), in which the radius C A is equal to A D, No. 1; and their lengths and bevels at their intersection with the front rib $l\ m$, $n\ o$, p (No. 1), or $e\ f\ k$, No. 2, will be obtained by transferring the lengths $r\ l$, $s\ m$, $t\ n$, $u\ o$, &c., from the plan No. 1 to the points $a\ b\ c\ d\ e$, &c., on the line A C, No. 3, and drawing the perpendiculars $a\ f$, $b\ g$, $c\ h$, $d\ i$, $e\ k$. The back rib $v\ w\ x$, No. 1, A B C, No. 2, and D, No. 3, is a circular segment, its outer edge described from the centre D, No. 1, with the radius D v, or with the radius C D, No. 3, and the curve of its inner edge with the radius D y, No. 1.

The front rib standing over A p C in the plan is a semi-ellipse, found as shown in Nos. 4, 5, 6. In No. 4 make

NICHES.

PLATE XVI



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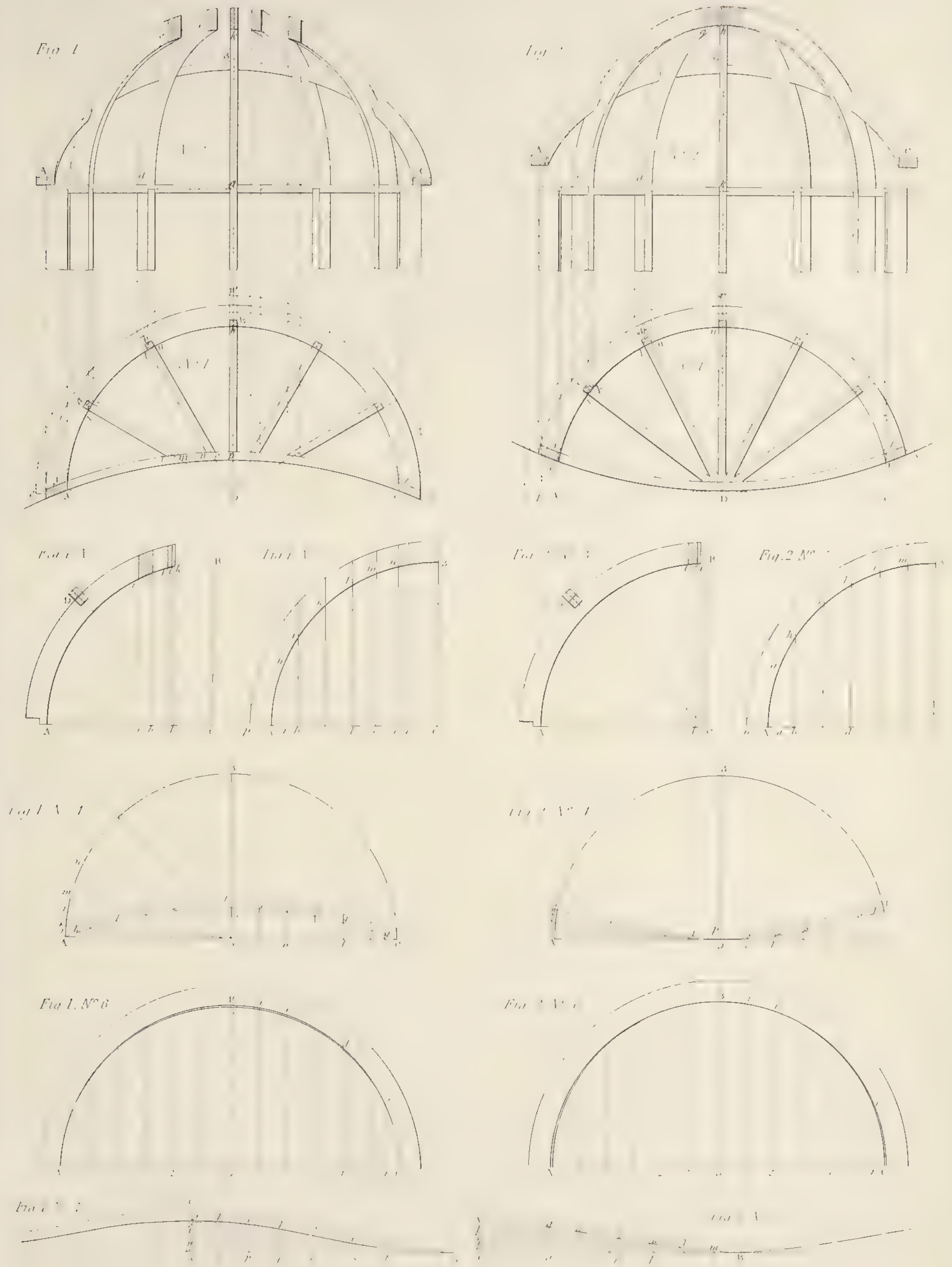


Fig. 1
Fig. 1. No. 6
Fig. 2 No.

A D C equal to A D C, No. 1; describe the semicircle A B C, draw D E B perpendicular to A C, and describe the curve of the wall A E C. The figure is thus a plan of the niche; and in like manner, in No. 5, A B C is an elevation of half the niche on the line A C of the plan, or it is a section on line B D of the plan. Divide the curve E A E C, No. 4, into a number of equal parts 1 2 3 4 5, and draw 1 *a*, 2 *b*, 3 *c*, 4 *d*, 5 *e*, perpendicular to A C, and transfer the lengths E 1, 1 2, 2 3, &c., from D towards A and C, on the line A D C, No. 6, and draw 1 *a*, 2 *b*, 3 *c*, &c., perpendicular to A C. To find the heights 1 *a*, 2 *b*, &c., transfer the divisions *a b c d e* of the line D C, No. 4, to *g e d c b* on the line A C, No. 5, and make C *f* equal to D *p*, No. 4. Then draw the perpendiculars *g o e m*, &c., and transfer the heights to the corresponding ordinates in No. 6, as *g o* to D B, *f n* to D *i*, *e m* to 1 *a*, *d l* to 2 *b*, &c.; and to complete the curve more exactly, divide the last space into two in the point *g*, No. 4; and draw *g f*, and transfer the points, in the same manner, to Nos. 5 and 6, for the ordinates *a h*, *g f*.

To find the mould for the front rib:—On the line A B, No. 7, make the divisions A *o p q r s t* B respectively equal to those of the curve *a b c d e f* C, No. 6; draw A *g*, *o h*, *p i*, *q k*, *r l*, *s m*, *t n*, perpendicular to A B, and make them equal respectively to D E, *a* 1, *b* 2, *c* 3, *d* 4, *e* 5, *fg*, No. 4; and through *g h i k l m n* B, draw the curve *g* B, which is the edge of the mould of the front rib.

The plan of a semicircular niche in a convex circular wall being given, to find the ribs.

Fig. 2: Let E B F (No. 1) be the plan of the niche, and E D F the curve of the wall. Draw the ribs *i k*, *l m*, *n*, &c., as in the last figure, and draw A C perpendicular to D B. In No. 2 the lines of the elevation are found in the manner indicated by the dotted lines. In No. 3 the lengths and bevel of the ribs are found as in the last problem; and Nos. 4, 5, 6, and 7 show the manner of describing the front rib and its mould, which must be so easily understood, if the construction of the foregoing figures has been comprehended, as not to require detailed description.

ANGLE BRACKETS.

Plate XIX.

Plate XIX.—*Let* C A B (*Fig.* 1) *be the elevation of the bracket of a cove, to find the angle bracket.*

First, when it is a mitre bracket in an interior angle, the angle being 45°, divide the curve C B into any number of equal parts 1 2 3 4 5, and draw through the divisions the lines 1 *d*, 2 *e*, 3 *f*, 4 *g*, 5 *c*, perpendicular to A B, and cutting it in *d e f g c*; and produce them to meet the line D E, representing the centre of the seat of the angle bracket; and from the points of intersection *h i k l c*, draw lines *h* 1, *i* 2, *k* 3, *l* 4, at right angles to D E, and make them equal—*h* 1 to *d* 1, *i* 2 to *e* 2, &c.; and through F 1 2 3 4 5 draw the curve of the edge of the bracket. The dotted lines on each side of D E on the plan show the thickness of the bracket, and the dotted lines *u r*, *v s*, *w t*, show the manner of finding the bevel of the face. In the same figure is shown the manner of finding the bracket for an obtuse exterior angle. Let D I K be the exterior angle: bisect it by the line I G, which will represent the seat of the centre of the bracket. The lines I H, *m* 1, *n* 2, *o* 3, *p* 4, *c* 5, are drawn perpendicular to I G, and their lengths are found as in the former case.

To find the angle bracket of a cornice for interior and exterior, otherwise re-entrant and salient, angles.

Let A A A (*Fig.* 2) be the elevation of the cornice bracket, E B the seat of the mitre bracket of the interior angle, and H G that of the mitre bracket of the exterior angle. From the points A *k a b c d* A, or wherever a change in the form of the contour of the bracket occurs, draw lines perpendicular to A *i* or D C, cutting A *i* in *e f g h i*, and cutting the line E B in E *l m n o* B. Draw the lines E G, G L and B H, H K, representing the plan of the bracketing, and the parallel lines from the intersections *l m n o*, as shown dotted in the engraving; then make B F and H I each equal to *i* A, *o u* to *h d*, *n t* to *g c*, *m s* to *f b*, *l r* to *e a*, *l p* to *e k*, and join the points so found to give the contour of the brackets required. The bevels of the face are found as shown by the dotted lines *x v y w*.

To find the angle bracket at the meeting of a concave curved wall with a straight wall.

Let A D B E (*Fig.* 3) be the plan of the bracketing on the straight wall, and D M, E G the plan on the circular wall; C A B the elevation on the straight wall, and G M H on the circular wall. Divide the curves C B, G H into the same number of equal parts; through the divisions of C B draw the lines C D, 1 *d h*, 2 *e i*, &c., perpendicular to A B, and through those of G H draw the parallel lines, part straight and part curved, 1 *m h*, 2 *n i*, 3 *o k*, &c. Then through the intersections *h i k l* of the straight and curved lines, draw the curve D E, which will give the line from which to measure the ordinates *h* 1, *i* 2, *k* 3, &c.

To find the angle bracket when the wall is a convex curve.

Let B E D C be the plan of the bracketing on the straight wall, and B E G H the plan on the curved wall. From the points A *k a b c d* A of the bracket A A A, where its contour changes, draw perpendiculars as before. Draw H G a radius to the curve of the wall H B, and set on it the divisions *o n m l*, equal and corresponding to *h g f e* of the elevation A A A; and draw H I, *o u*, *n t*, *m s*, *l r*, *l p*, perpendicular to G H, and make them equal to *i* A, *h d*, *g c*, *f b*, *e a*, *c k*, of the elevation; then join the points by the lines I *u*, *u t*, *t s*, *s r*, *r p*, *p* G, to obtain the contour of the bracket equal and corresponding to A A A. Through the points *o n m l* draw concentric curves, meeting the perpendiculars from the corresponding points of A A A; from the intersections of the straight and curved lines, *o n m l*, draw the lines B F, *o u*, *n t*, *m s*, *l r*, perpendicular to E B, and make them equal to the corresponding lines of the elevation, as before; then join the points F *u t s r p* E, to obtain the contour of the angle bracket.

The examples in *Figs.* 5 and 6 do not require further elucidation.

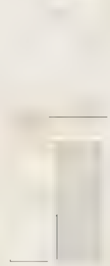
FORMS OF ROOFS.

The most simple form of a building is one erected on a rectangular plan, with two long and two short sides. Such a building is roofed generally, either with a roof of a single slope, called a shed roof, as in Fig. 351—the wall of one of the long sides of the building being carried so much higher than the wall parallel with it, as to give the

required slope to the roof—or with a roof of double slope, as in Fig. 352.

Fig. 351.

Fig. 352.



In the latter, the planes forming the slopes are equally inclined to the horizon; the meeting of their highest sides makes an arris, which is called the ridge of the roof; and the triangular spaces in the end walls are called gables.

When a building is erected on a rectangular plan, of which the four sides are equal, it may be covered with a roof of two slopes. But it may happen that no necessity may exist for making any of the opposite pairs of sides gables; or there may be reason why all the sides should be gables. In the latter case, two roofs of equal slope intersect each other. This roof, then (Fig. 353), has two ridges *a b*, *c d*, and four hollow arrises *f e*, *g e*, *h e*, *k e*, made by the intersections of the planes of the slopes, and lying over the diagonals of the square. The arrises are

Fig. 353.

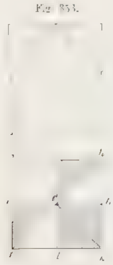
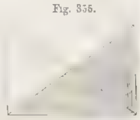


Fig. 354.

termed valleys or flanks. In the former case, a mode much more simple, and often preferable, because simpler in construction, is to make each of the sides of the roof spring from the sides of the square with an equal slope. The result (Fig. 354) is a pyramid more or less obtuse or acute, and the intersections of the sloping planes form salient angles, or arrises. This kind of roof is called a pavilion roof. If its base be formed by a polygon, of which the sides are equal, the pyramid will be composed of as many triangles as the polygon has sides. The arrises are also called hips.

When the sides of a parallelogram on which a building is raised are not very unequal, it may be roofed with a pavilion roof, as in Fig. 355; the slopes on corresponding and opposite sides being equal, but those on contiguous sides different.

Fig. 355.



The pavilion roof is applied also to buildings erected on oblong plans. Thus, in the roof (Fig. 356) the sides *a b*, *c d*, are truncated at their higher extremities by sides of the same slope rising from the ends *c a*, *d b*. These form, by their meeting with the former, the arrises or hips *a f*, *c f*, *b c*, *d e*, and the form which results at each end

Fig. 356.

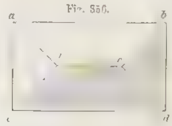
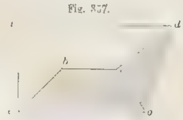


Fig. 357.



is called a hip. The roof is called a hipped roof, and the rafters on the lines of the arrises are called hip-rafters. When the end of such a roof is at right angles to its side, as *a b e* (Fig. 357), it is called a right hip; when the angles are unequal, as at *d c o*, it is an oblique or skewed hip.

When the plan of a building is composed of two equal parallelograms crossing each other at right angles, each of the parallelograms may be covered with a roof of two slopes and two gables, as in Fig. 358, or they may each

Fig. 358.

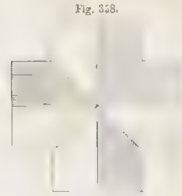
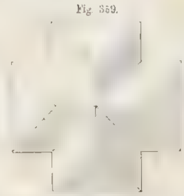


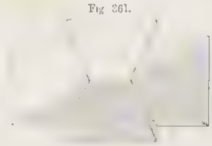
Fig. 359.



be covered with a hipped roof, as in Fig. 359; in each case forming four valleys at their intersections. When the intersecting parallelograms are unequal in length, the

Fig. 360.

Fig. 361.



shortest may be roofed pyramidally, the slopes of its contiguous sides being unequal, and the longest with a ridge, as in Fig. 360; or there may be a short ridge common to both, as in Fig. 361.

Figs. 362 and 363 are plans of roofs having valleys, hips, and ridges,—the slopes in both being unequal.

Fig. 362.

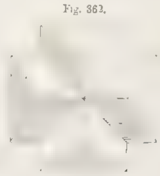
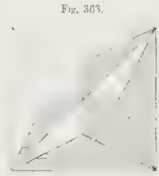


Fig. 363.

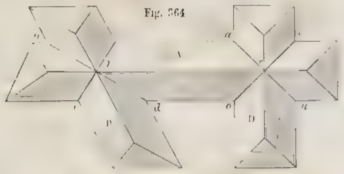


Great edifices are often composed of several masses of building, which form diverse angles with each other; and their extremities may also abut upon streets and roads at various angles. Ordinarily, the different ranges of the building have their crowning cornice on the same level, and their roof of the same height.

In Fig. 364 is represented the horizontal projection of the roofs of a building composed of three ranges crossing each other. Their six extremities, square or skewed, are hipped, according to the form of the plan. The lines formed by the intersections of the roofs are valleys. The valleys *c a*, *c e*, *c o*, *c u* are equal, because the buildings A and D are equal in width, and cross each other at

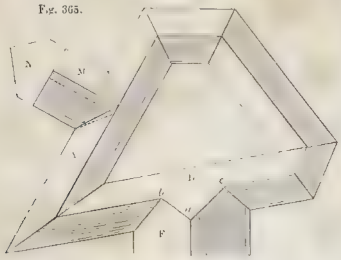
right angles. The valleys $b\,c$, $b\,d$, $b\,f$, $b\,g$ are unequal, because the angles formed by the intersecting buildings are not 90°. In this combination of roofs the hips occur together in pairs, and the valleys four and four. In the

Fig. 364.



next figure (Fig. 365) the ranges of building inclose a court. Their meeting forms hips on the exterior and

Fig. 365.



valleys in the interior. All the hips divide the angles to which they correspond into two equal parts In the same way the valleys divide the interior angle into equal parts; and in general the hips and valleys are equal when they result from the meeting of two ranges of buildings of the same width, with roofs of equal height; but they become irregular when the buildings are of unequal width, though of the same height, or when the opposite sides of the roofs are of different slopes. At the range of building M in the figure, which meets the range A at right angles, the slopes, and consequently the valleys, are unequal, the inequality being proportionate to the deviation from the dotted lines; and the gable is also irregular, as shown by the section N. When the greater width of a building causes its roof to rise higher than the roof which it meets, as the roof of the wide range F meeting D, the connection is completed by extending the slope of D so as to truncate the summit of F, and form the hips $b\,a$, $c\,a$.

When two buildings of unequal width meet each other, and the ridges of the roofs are not kept of equal

Fig. 366.

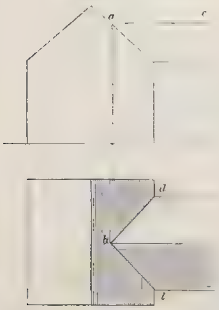
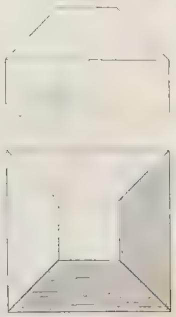
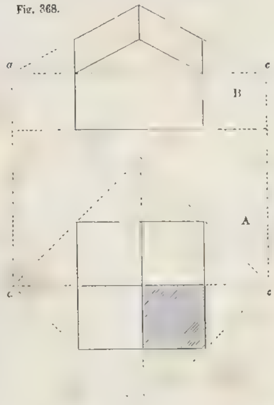


Fig. 367.



height, as in Fig. 366, the horizontal projection of the lower roof is found by drawing a line $a\,b$ from the point in the vertical projection a, where the line of the ridge $a\,c$ of the lower roof meets the slope of the higher roof, to the seat of the ridge on the plan below, and joining $b\,d$, $b\,d$ for the valleys formed by the intersections. When the slopes are equal, as in the figure, $d\,b\,d$ will be a right angle.

Fig. 368.



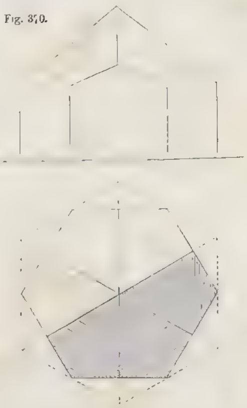
In Fig. 367 is shown a pavilion roof, truncated by a plane parallel to its base.

Fig. 368, A is the horizontal, and B the vertical projection of a square building, presenting four equal gables and as many equal slopes; but the intersections of the slopes, in place of lying over the diagonals of the square, connect together the summits of the gables. This roof, it

Fig. 369.

will be seen by the dotted lines, is the section of a pyramidal roof $a\,b\,c$, made by four planes parallel to its diagonal.

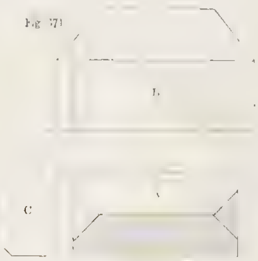
Fig. 370.



The combination of hips and gables may be used for figures of any number of sides. If the number of sides is even, the sides may be alternately gabled and horizontal, as in Fig. 369, the plan of which is a hexagon, the result of the truncation of a triangular pyramid by planes parallel to its opposite sides. Where each side has a gable, as in Fig. 370, the resulting figure is a hexagonal pyramid truncated by six planes, forming gabled sides.

In Fig. 371, A is the horizontal projection of a roof with hips or pavilion ends, truncated; B is the vertical projection of the side, and C that of the end.

Fig. 371.



When it is desirable to keep the roofing over a wide building of a rectangular plan low, it may be effected by dividing the span into two, with four principal slopes, two external and two internal. This, which produces a section somewhat resembling the letter M (Fig. 372), is, from its form, called an M-roof. At the meeting of the interior slopes is formed a gutter for the water. Fig. 373 is the horizontal projection of such a roof with gables, and Fig. 374 the same with hips.

Fig. 372.

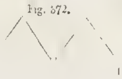
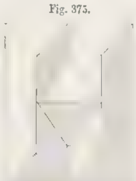


Fig. 373.

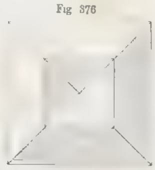
Fig. 374.

Fig. 375.



In order to avoid the long gutter, another roof is sometimes introduced, as in Fig. 375, crossing between the two ridges at right angles, and forming valleys by the intersection of its slopes with the interior slopes of the longitudinal roofs; and for the sake of external appearance, or to collect the water in the centre, two cross roofs are sometimes used, inclosing a central space. When the interior slopes meet in a point, as in Fig. 376, the roof is called a hopper roof.

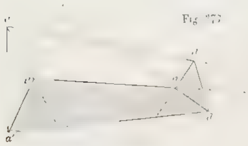
Fig. 376.



Sometimes the plan of a building is irregular, and its sides are not parallel. If the roof be constructed so that the ridge slopes to the narrow end, its sides will be planes; but if the ridge be made horizontal throughout, the sides of the roof will become twisted or winding.

Let *a d d′ a′* (Fig. 377) be the plan of an irregular

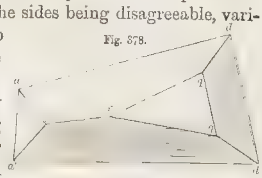
Fig. 377.



building. The roof is hipped, having sloped ends forming the two triangles *a p a′*, *d g d*, which may be isosceles; and the ridge is projected on the line *p g*, which is not parallel to either of the sides *a d*, *a′ d′*. Two cases here present themselves: the ridge projected on *p g* is either horizontal, and its extremities are determined by its meeting with the planes of the sloping ends, which may have the same slope—the larger sides in this case being twisted; or it has an inclination determined by the intersection of the planes *a p g d*, *a′ p g d′*, springing with equal slopes from the wall head. It is easy to observe that the ridge will not in either case appear parallel to the faces of the building. Of these two methods, the most agreeable to the sight is the first, in which the ridge is horizontal: it is also the most economical in construction. The two greatest sides of the roof are surfaces generated by a line which, moving from *a d* or *a′ d′*, to meet the ridge *p g*, is kept in contact with a vertical line passing through *c* or *c′*, where the arrises of the hips meet when produced.

The twist or wind of the sides being disagreeable, various methods are used to get rid of it where the ridge is horizontal.

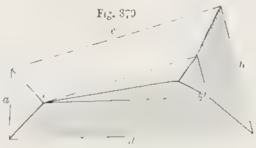
Fig. 378.



In Fig. 378, two equally inclined planes spring from *a d*, *a′ d′*, and their intersection produces an inclined ridge *p f*. The points *q q* are taken at the level of *p*, and the arris *f q* is thus symmetrical with *f p*.

The same plan may be covered by a roof with horizontal ridges, as in Fig. 379. The four sides of the roof are planes, springing at the same inclination from the walls *a b c d*. The ridges *e f* *e g*, are continued at the height determined by the intersection of the hip at *e*; and a pyramidal construction, *e f g*, is added, at so low a pitch as not to be visible from the ground. In place of these pyramidal roofs, the three sides of the building *c b d* may have roofs of two slopes intersecting at the lines *e h*, *h f*, *h g*, forming what is called an irregular hopper roof.

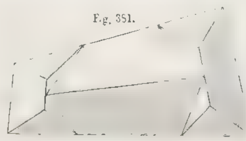
Fig. 379.



In Fig. 380, another method of preserving the ridge horizontal on one side without twisting the sides, is shown. In this case one of the sides is roofed in two slopes forming an arris, *a b*.

Fig. 380.

Fig. 381.



In Fig. 381, another method of roofing the same space is shown.

The Figs. 382 to 386 show various methods of roofing a

Fig. 382.

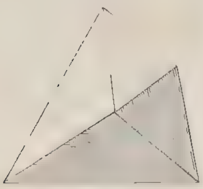


Fig. 383.

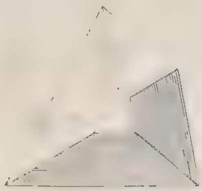


Fig. 384.

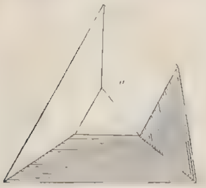


Fig. 385.

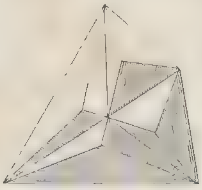
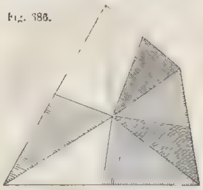


Fig. 386.



trapezium without twisting the sides. In Fig. 382, the sides are planes, and form an irregular pavilion roof. In Fig. 383, planes of the same slope rise to the same height, and are united by a platform. In Fig. 384, one side, *a*, is twisted. In Fig. 385, two irregular pavilion roofs cross each other, forming valleys at their intersections. In Fig. 386 there are four gables and four valleys, as in the roof over a square plan, Fig. 353.

In the roofs over an oval plan, Fig. 387 shows one

Fig. 387.

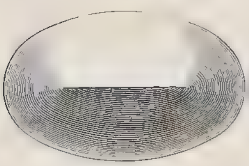
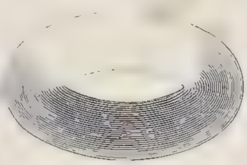


Fig. 388.



with a straight and horizontal ridge, and, consequently, with twisted sides; but in this case the appearance of the side is not disagreeable.

In Fig. 388, the sides are not twisted, but slope everywhere alike; and the roof is truncated and terminated by a platform.

Fig. 389 is a conical roof.

Fig. 390 is a roof over a rectangular plan, with a

Fig. 389.

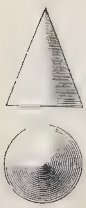


Fig. 390.

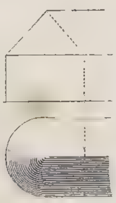
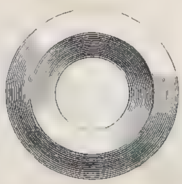


Fig. 391.



semicircular end. The end of the roof is consequently a semi-cone.

Fig. 391 is an annular roof.

Fig. 392 is the roof of a crescent building, with one end gabled and the other hipped.

Fig. 392.

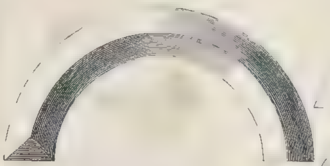


Fig. 393.

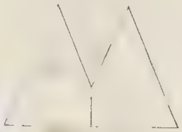


Fig. 394.

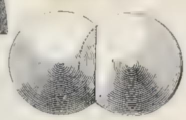


Fig. 393 is the vertical, and Fig. 394 the horizontal projection of two united conical roofs.

Fig. 395 is the junction of a large and a small conical roof.

Fig. 395.

Fig. 396.

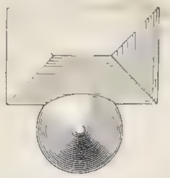


Fig. 396 is the junction of a conical and a pavilion roof.

Fig. 397 is the junction of a span roof with a large conical roof.

Fig. 398 shows the junction of a conical and a crescent roof.

Fig. 399 shows the junction of a conical with an annular roof.

In Fig. 400, A is the horizontal, and B the vertical projection of a round pavilion roof, formed by a conical roof cut

Fig. 397

Fig. 398

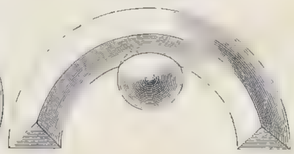
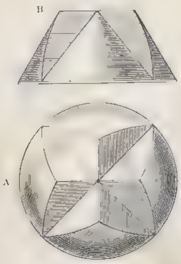


Fig. 399

Fig. 400.



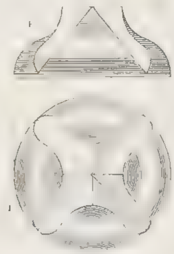
by two span roofs, which give two horizontal ridges, four right-lined valleys, and eight hips, which are elliptic curves.

In Fig. 401, C is the horizontal, and D the vertical pro-

jection of a round pavilion roof, formed by a hemispherical cupola cut by two span roofs, making two horizontal ridges, four right-lined valleys, and eight hips, which are arcs of circles.

Fig. 401.

Fig. 402.



In Fig. 402, E and F are the horizontal and vertical projections of an imperial pavilion made in the same manner.

In Fig. 403, G and H are the horizontal and vertical sections of a roof in the form of a hemisphere, truncated by four inclined planes, forming a pavilion roof with four right-lined arrises, and eight arrises of portions of circles.

Fig. 403.

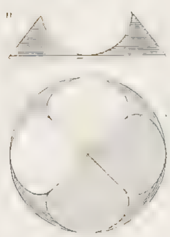


Fig. 404.

In Fig. 404, I and K are the horizontal and vertical projections of a round pavilion, formed by the truncating of a cone by four inclined planes. This is of the same

Fig. 405.

kind as the last, only the curves of the arrises are portions of ellipses.

In Fig. 405, A is a horizontal, and B a vertical projection of a conical roof, whose summit is at c, truncated by two sloping planes, forming a horizontal ridge $a\ b$, and four hips having elliptic arrises $a\ d$, $a\ c$, $b\ d$, $b\ c$.

Fig. C is a second vertical projection, on a plane parallel to $c\ d$.

In Fig. 406, A and B are the horizontal and vertical projections of a conical roof truncated interiorly by two inclined planes.

Fig. 406.

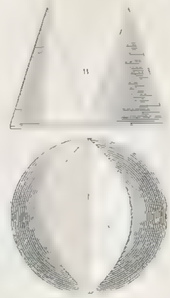


Fig. 407.

In Fig. 407, A is a horizontal projection of a roof, formed by the setting of a square pyramidal roof diagonally on a pavilion roof of lower elevation. This is the broach or spire of Gothic architecture. B is the vertical projection on a plane parallel to one of the faces of the lower pyramid, and C the vertical projection on a plane parallel to its diagonal.

In Fig. 408, A is the horizontal, and B the vertical projection of a pyramidal roof with a square base, set on an octagonal pavilion roof of lower elevation.

In Fig. 409, A is the horizontal, and B the vertical projection of a pyramidal roof, with an octagonal base, set on a pavilion roof of lower pitch with a square base.

Fig. 408.

Fig. 409.

In Fig. 410, A and B are the horizontal and vertical projections of a conical roof set on a square pyramid.

In Fig. 411, A and B are the horizontal and vertical projections of an acute conical roof set on an octagonal pyramid.

In Fig. 412, A is the horizontal, and B the vertical pro-

jection of a roof formed by an octagonal pyramid set on a cone.

Fig. 410.

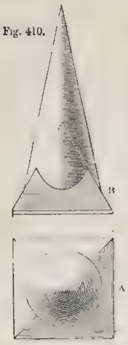
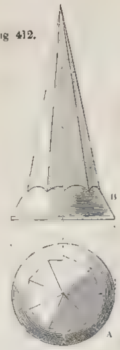


Fig. 411.

Fig. 412.



In Fig. 413, A is the horizontal, and B the vertical projection of a roof formed by an acute cone set on an obtuse one.

In Fig. 414, A and B are two projections of two conical spires set on a conical roof.

Fig. 413.

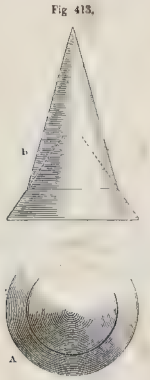
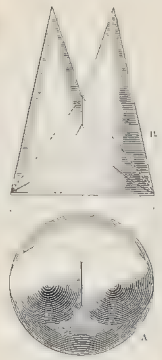


Fig. 414.



We shall now proceed to describe the methods of determining the places and forms of the rafters in such hip-roofs as are of most common occurrence in practice.

HIP-ROOFS.

Plates XX., XXI.

In its most simple form the *hip-roof* is a quadrilateral pyramid, each triangular side of which is a *hip*, and the rafter in each angle is a *hip-rafter*. The *common rafters* which lie between the hip-rafters in the planes of the sides of the roof, and which, by abutting on the hip rafters, are necessarily shorter than the length of the sloping side, are called *jack-rafters*.

The things required to be determined in a hip-roof are these, viz.:—

1. The angle which a common rafter makes with the plane of the wall-head; that is, the angle of the slope of the roof.
2. The angle which the hip-rafters make with the wall head.
3. The angles which the hip-rafters make with the adjoining planes of the roofs. This is called the backing of the hip.
4. The height of the roof.
5. The lengths of the common rafters.
6. The lengths of the hip-rafters.
7. The length of the wall-plate contained between the hip-rafter and next adjacent entire common rafter.

The first, fourth, fifth, and seventh of these are generally given, and then all the others can be found from them by construction, as is about to be shown.

The plan of a building and the pitch of the roof being given, to find the lengths of the rafters, the backing of the hips, and the shoulders of the jack rafters and purlins.

Plate XX.—Let A B C D (*Fig.* 1) be the plan of the roof. Draw G H parallel to the sides A D, B C, and in the middle of the distance between them. From the points A B C D, with any radius, describe the curves *a b*, *a b*, cutting the sides of the plan in *a b*. From these points, with any radius, bisect the four angles of the plan in *r r r r*, and from A B C D, through the points *r r r r*, draw the lines of the hip-rafters A G, B G, C H, D H, cutting the ridge line G H in G and H, and produce them indefinitely. The dotted lines *c e*, *d f*, are the seats of the last entire common rafters. Through any point in the ridge line I, draw E I F at right angles to G H. Make I K equal to the height of the roof, and join E K, F K: then E K is the length of a common rafter. Make G *o*, H *o* equal to I K, the height of the roof; and join A *o*, B *o*, C *o*, D *o*, for the lengths of the hip-rafters. If the triangles A *o* G, and B *o* G, be turned round their seats, A G, B G, until their planes are perpendicular to the plane of the plan, the points *o o*, and the lines G *o*, G *o*, will coincide, and the rafters A *o*, B *o* be in their true positions.

Let A B C D (*Fig.* 2) *be the plan of an irregular roof, in which it is required to keep the ridge level.*

Bisect the angles of two ends by the lines A *b*, B *b*, C G, D G, in the same manner as before; and through G draw the lines G E, G F parallel to the sides C B, D A respectively cutting A *b*, B *b* in E and F; join E F: then the triangle E G F is a flat, and the remaining triangle and trapeziums are the inclined sides. Join G *b*, and draw H I perpendicular to it: at the points M and N, where H I cuts the lines G E, G F, draw M K, N L perpendicular to H I, and make them equal to the height of the roof: then draw H K, I L for the lengths of the common rafters. At E, set up E *m* perpendicular to B E; make it equal to M K or N L, and join B *m* for the length of the hip-rafter; and proceed in the same manner to obtain A *m*, C *m*, D *m*.

To find the hip and valley rafters of a compound irregular roof (*Fig.* 3).

In the compound roof shown by the plan, in which the ridge is level throughout, although the buildings are of different widths, the method of proceeding to find the hip and valley rafters of the right-lined parts of the roof is the same as in the two former cases, and will be evident on inspection. In the circular part, proceed as follows:—Draw *c d* a radius to the curve, as the seat of one pair of the common rafters *c b*, *d b*, and bisect it in *a*: through *a* describe the curve *k a* W *n a*, which is the seat of the circular ridge: produce the lines of the other ridges to meet this curved line in *a* W *k*, and connect the angles of the meeting roofs with these points, as in the drawing: divide the seat of one pair of the common rafters in each roof, as X Y, P Q, T U, and *e f*, into the same number of equal parts; and through the points of division

draw lines parallel to the sides of their respective roofs, intersecting the curved lines drawn through the points of the curved roof; and through the points of intersection draw the curves C, l, m, a, &c., which give the lines of the hips and valleys. On C a, the meeting of the left-hand roof with the circular roof, erect $a\,b$ at a, and make it equal to the height of roof; and join C b, for length of valley rafter: proceed in the same manner for the hip-rafter Z b; and for the other hip and valley rafters.

To find the valley rafters at the intersection of the roof B *with the conical roof* E (*Fig.* 4).

Let D H, F H be the common rafters of the conical roof, and K L, I L, the common rafters of the smaller roof, both of the same pitch. On G H set up G e equal to M L, the height of the lesser roof, and draw $e\,d$ parallel to D F, and from d draw $c\,d$ perpendicular to D F. The triangle D $d\,c$, will then by construction be equal to the triangle K L M, and will give the seat and the length and pitch of the common rafter of the smaller roof B. Divide the lines of the seats in both figures, D c, K M, into the same number of equal parts; and through the points of division in E, from G as a centre, describe the curves $c\,a$, $2\,g$, $1\,f$, and through those in B, draw the lines $3\,f$, $4\,g$, M a, parallel to the sides of the roof, and intersecting the curves in $f\,g\,a$. Through these points trace the curves C $f\,g\,a$, A $f\,g\,a$, which give the lines of intersection of the two roofs. Then to find the valley rafters, join C a, A a; and on a erect the lines $a\,b$, $a\,b$ perpendicular to C a and A a, and make them respectively equal to M L; then C b, A b is the length of the valley rafter, very nearly.

PLATE XXI. *Fig.* 1—*Shows the method of finding the backing of the hip-rafter.*

Let B b, b C be the common rafters, A D the width of the roof, and A B equal to one half the width. Bisect B C in a, and join A a, D a. From a set off $a\,c$, $a\,d$ equal to the height of the roof $a\,b$, and join A d, D c; then A d, D c are the hip-rafters. To find the backing: from any point h in A d, draw the perpendicular $h\,g$, cutting A a in g; and through g draw perpendicular to A a the line $e\,f$, cutting A B, A D in e and f. Make $g\,k$ equal to $g\,h$, and join $k\,e$, $k\,f$; the angle $e\,k\,f$ is the angle of the backing of the hip-rafter C.

Fig. 2.—Where the angles of the roof are not right angles. Bisect A D in a, and from a describe the semicircle A b D; draw $a\,b$ parallel to the sides A B, D C, and join A b, D b, for the seat of the hip-rafters. From b set off on b A, b D, the lengths $b\,d$, $b\,e$, equal to the height of the roof $b\,c$, and join A e, D d, for the lengths of the hip-rafters. To find the backing of the rafter:—In A e, take any point k, and draw $k\,h$ perpendicular to A e. Through h draw $f\,h\,g$ perpendicular to A b, meeting A B, A D in f and g. Make $h\,l$ equal to $h\,k$, and join $f\,l$, $g\,l$; the angle $f\,l\,g$ is the backing of the hip.

To find the bevel of the shoulder of the purlins.

Fig. 3.—First, where the purlin has one of its faces in the plane of the roof, as at E. From c as a centre, with any radius, describe the arc $d\,g$; and from the opposite extremities of the diameter, draw $d\,h$, $g\,m$ perpendicular to B C. From e and f, where the upper adjacent sides of the purlin produced cut the curve, draw $e\,i$, $f\,l$ parallel to to $d\,h$, $g\,m$; also draw $c\,k$ parallel to $d\,h$. From l and i draw $l\,m$ and $i\,h$ parallel to B C, and join $k\,h$, $k\,m$. Then $c\,k\,m$ is the down bevel of the purlin, and $c\,k\,h$ is its side bevel.

When the purlin has two of its sides parallel to the horizon. This simple case is shown worked out at F. It requires no explanation.

When the sides of the purlin make various angles with the horizon. *Fig.* 4 shows the application of the method described in *Fig.* 3, to these cases.

Fig. 5 *shows the method of finding the bevel of the jack-rafters.*

Let A B C D be the plan. Draw the hipped end of the roof A E D in any of the manners already described. Bisect B C in E; and from E as a centre, with the radius E C, describe the semicircle C I d. Through E draw $d\,e$ parallel to A D. Bisect the semicircle $d\,e$ in I, join E I, and produce the line to G; E I represents the seat of the common rafter, extending from the wall plate to the junction of the hip-rafters, and the length of the rafter over the seat will of course be equal to B a or C a. Make I G, therefore, equal to B a or C a, and join A G, D G. The triangle A G D will then show the extent of the covering of the hip A E D, and A G, D G give the lengths of the hip-rafters.

Produce B C to F and H, and make B F, C H each equal to the length of the common rafter C a or B a, and join A F, D H. The triangle A F B is the covering of the triangle A E B, and D H C of D E C.

To find the bevel of any jack-rafter on the hip A E D:—From its seat on the plan, shown in dotted lines $g\,o$, $h\,p$, draw the parallel lines $g\,k$, $h\,l$ to the line of the hip-rafter A G in the development, and $k\,l$ shows the bevel of the jack-rafter on the hip-rafter. Any of the other jack-rafters are found in the same way, as shown by the dotted and shaded lines. The down bevel of all the jack-rafters is the angle C a E.

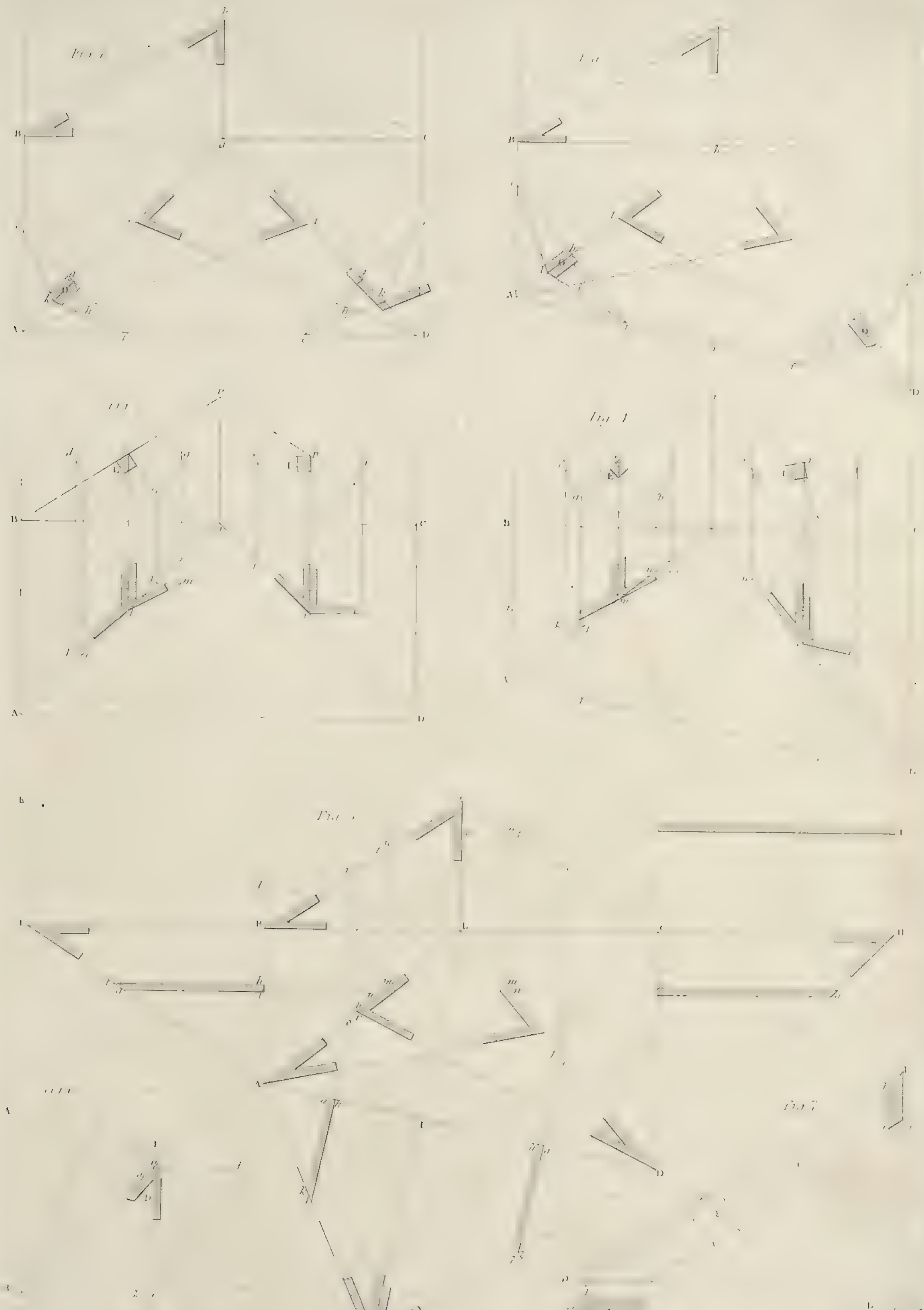
Fig. 6 *shows the method of finding the length and bevel of any single jack-rafter.*

Let A B C be the plan of one angle of a hip-roof, and B E the seat of the hip-rafter. It is required to find the length and bevel of the jack-rafter over the seat D $k\,e$. At the point b, where the longest side of the jack-rafter meets the hip-rafter, draw $b\,d$ at right angles to side of jack-rafter $b\,e$, and make the angle $b\,e\,d$ equal to the slope of roof; draw also $b\,c$ at right angles to side of hip-rafter $a\,b$, and make it equal to $b\,d$. Produce $b\,e$, $h\,k$ indefinitely, and make $b\,g$ equal to $d\,e$; and $h\,b$, $f\,g$ is the length of the jack-rafter. To obtain the bevel at $h\,b$, draw $a\,l$ at right angles to B C and make it equal to $k\,f$ or $e\,g$, and join $b\,l$; then the angle $l\,b\,g$ is the bevel of the jack-rafter.

To find the bevel of a hip-rafter made by a plane parallel to the planes of the common rafters.

Let A (*Fig.* 7) be the seat of the foot of the rafter, B the horizontal projection of its upper end, $l\,m$ the projection of the bevel there, and C the vertical projection of the rafter on a plane parallel to its plane. The backing of the rafter $b\,a\,d$ at A, and its cross section $r\,u\,q\,v\,s$ at F, will be evident without description. The method of finding the bevel at $g\,k$ E h is as follows:—From g draw the horizontal line $g\,i$, and from g as a centre, with the radius $g\,h$, describe the arc $h\,i$. From i let fall a perpendicular $i\,n$ to the horizontal projection meeting B m produced in n, then draw $l\,n\,o$, and $p\,l\,o$ is the proper bevel.

ROOFS.



PART FOURTH.

KNOWLEDGE OF WOODS—THEORETICAL CARPENTRY.

PHYSIOLOGICAL NOTIONS.

THE substance named *wood* is, for the most part, elastic, tenacious, durable, and easily fashioned—qualities which cause it to be in general request for articles of use and of luxury. It is used as fuel, either in its natural state or as reduced to charcoal: it also affords tar, to produce which, much of it is annually consumed.

Wood* has always been indispensable in the arts. Iron, from its power of resisting cutting instruments and the attacks of fire, has, in some measure, rivalled it; but wood must still be regarded as the substance which contributes most to the preservation of man, to his defence, his civilization, and the development of his power. It enters largely into the fabrication of tools and machines, of arms of warfare, of furniture and utensils, and of all kinds of constructions, from the modest hut, the small footbridge and frail skiff, to the grandest edifices, bridges of daring span, and mighty ships which extend man's commerce and his power, and bring together those whom nature would seem to have separated for ever.

In the Art of Carpentry, above all, timber is employed in the manner most remarkable, and in the largest masses. The natural form of the tree admits of the timber being obtained in long parallelopipedons, termed beams, girders, &c., the combination and framing of which constitute the means of raising great structures in the most rapid manner.

It is not necessary, for the purposes of this work, to enter minutely into the discussion of the subject of vegetable physiology: all that is here requisite, is to state some of the more important facts, the knowledge of which is of consequence to the carpenter who desires to possess the power of discernment in the choice of timber.

The part that is characterized as *timber* is obtained from the body of trees, or that part of those which grow with a thick stem, rising high, and little encumbered with branches or leaves, which is called the *trunk*. The *head* of the tree consists of the branches, which are adorned with leaves: these attain their full development in the summer, and then, in the great majority of species, fall in the autumn.

In carpentry, the wood of the trunk and largest branches alone is used; and only that of the commoner species of trees; leaving to other arts to employ that of the rarer and smaller kinds, for which their beauty, rather than strength, is the recommendation.

Some of the timber trees attain an immense size when they are allowed to come to full maturity of growth. Oaks and beeches are found to attain the height of 120 feet; the larch, the pine, the fir grow to the height of 135 feet. Other kinds, as the elm, the aspen, the maple, the alder, and even the walnut, the poplar, and the cypress, reach sometimes a great elevation. In warm regions, the palm grows as large as the oak. The diameter of the trunk varies with the kind and the climate. Oaks and elms may be seen of the enormous size of 36 feet in circumference.

Farner mentions an elm at Hasfield, in Massachusetts, considered the largest in America, which measured, at the surface of the ground, 34 feet in diameter; and at 5 feet high, 24 feet. Condamine speaks of canoes on the Amazon river made of single trees, and measuring 90 palms in length, and 10 in width. Other authors mention trees of equally great dimensions, such as the firs of North America, which shoot up to 250 feet in height; and cypresses, which grow to 7 and 8 feet in diameter.

The Carolina pine is said to attain a size still more astonishing, the trunk growing to 60 feet in circumference, and rising 300 feet before the head is formed.

The diameter which trees attain in our climate, however, rarely exceeds 5 feet, and ordinarily they are found of half that size.

Ship-building consumes a great quantity of timber. For this service, the curved pieces are more useful; but it seizes also upon the finest trees; which renders it difficult to satisfy the wants of the other branches of carpentry, and creates occasion for divers expedients to supply the want of size in the timber, both in length and sectional area. The difficulty of procuring oaks of sufficient magnitude has directed attention to pines and firs.

Botanists classify vegetables, and consequently trees, according to their physiological and structural peculiarities; and in this way trees are divided into two great classes,—Monocotyledonous, or Endogenous, and Dicotyledonous, or Exogenous trees.

The terms Monocotyledonous and Dicotyledonous, belong to the Jussieuan system of nomenclature, and are descriptive of the organization of the seeds. Endogenous and Exogenous are the terms used by modern botanists, and are descriptive of the manner of growth or develop ment of the woody matter of the tree, which is, in the endogens, from the outside inwards towards the interior, and in the exogens, outwards to the exterior.

The monocotyledonous or endogenous trees are only used in this country in the formation of articles of luxury. Trees of this class have no branches: their stems, nearly cylindrical, rise to a surprising height, and are crowned by a vast bunch of leaves, in the midst of which grow their flowers and fruits. In this class are the palm trees, growing only, in their native luxuriance, in tropical climes, where they are of paramount importance, yielding to the people of those countries meat, drink, and raiment, and timber for the construction of their habitations.

The palm tree will serve as a type of the endogenous structure. Dr. Lindley† says of it—"In the beginning, the embryo of the palm consists of a cellular mass, of a cylindrical form, very small, and not at all divided. As

* Colonel Emy, abridged and slightly altered.

† Lindley's *Vegetable Kingdom*, p. 95.

soon as germination commences, a certain number of cords, of ligneous fibre, begin to appear in the radicle,* deriving their origin from the plumule.† Shortly afterwards, as soon as the rudimentary leaves of the plumule begin to lengthen, spiral and dotted vessels appear in the tissue in connection with the ligneous cords; the latter increase in quantity as the plant advances in growth, shooting through the cellular tissue, and keeping parallel with the outside of the root. At the same time, the cellular tissue increases in diameter, to make room for the ligneous cords (or woody bundles, as they are called). At last a young leaf is developed, with a considerable number of such cords in connection with its base; and as its base passes all round the plumule, those cords are, consequently, connected equally with the centre which that base surrounds. Within this a second leaf gradually unfolds, the cellular tissue increasing horizontally at the same time; the ligneous cords, however, soon cease to maintain anything like a parallel direction, but form arcs, whose extremities pass upwards and downwards, losing their extremities in the leaf on the one hand, and in the roots on the other, or in the cellular integument on the outside of the first circle of cords; at the same time, the second leaf pushes the first leaf a little from the centre towards the circumference of the cone of growth. In this manner, leaf after leaf is developed, the horizontal cellular system enlarging all the time, and every successive leaf, as it forms at the growing point, emitting more woody bundles curving downwards and outwards, and, consequently, intersecting the older arcs at some place or other; the result of which is, that the first formed leaf will have the upper end of the arcs which belong to it longest and much stretched outwardly, while the youngest will have the arcs the straightest; and the appearance produced in the stem will be that of a confused entanglement of woody bundles in the midst of a quantity of cellular tissue. As the stem extends its cellular tissue longitudinally while this is going on, the woody arcs are, consequently, in proportion, long, and, in fact, usually appear to the eye as if almost parallel, excepting here and there where two arcs intersect each other. As, in all cases, the greater number of arcs curve outwards as they descend, and eventually break up their ends into a multitude of fine divisions next the circumference, where they assist in forming a cortical integument, it will follow, that the greater part of the woody matter of the stem will be collected near the circumference; while the centre, which is comparatively open, will consist chiefly of cellular tissue; and when, as in many palms, the stem has a limited circumference, beyond which it is not its specific nature to distend, the density of its circumference must, it is obvious, be proportionably augmented.

"Never is there any distinct column of pith or medullary rays, or concentric arrangement of the woody arcs; nor does the cortical integument of the surface of endogenous stems assume the character of bark separating from the wood below it: on the contrary, as the cortical integument consists very much of the finely divided extremities of the woody arcs, they necessarily hold it fast to the wood, of which they are themselves prolongations; and the cortical integument can only be stripped off by tearing it away from the whole surface of the wood, from which it does not separate without leaving myriads of little broken threads behind."

Such is the general structure of the most perfect among the endogens, a family of plants which, in this country, are little known as trees; but which, in the cereal and other grasses, enter largely into cultivation as articles of food for men and animals. In other countries, however, the endogenous trees fill an important place in structural economy, as well as contribute largely to the food of man. One of them, the bamboo, plays so many parts, as absolutely to make it difficult to say what it is *not* used for. A recent writer enumerates some of its most common uses in China, in the following amusing manner:—

"Bamboo is used in making soldiers' hats and shields, umbrellas, soles of shoes, scaffolding poles, measures, baskets, ropes, paper, pencil-holders, brooms, sedan chairs, pipes, flower-stalks, and trellis-work in gardens: pillows are made of the shavings: a kind of cloak for wet weather is made of the leaves. It is used for making sails and covers for boats, fishing rods and fishing baskets, fishing stakes and buoys, aqueducts for water, water wheels, ploughs, harrows, and other implements of husbandry. Its roots are cut into grotesque figures, and its stem carved into ornaments for the curious, or as incense-burners for the gods. The young shoots are boiled and eaten; and sweetmeats are also made of them. A substance found in the joints, called *tabasheer*, is used in medicine. In the manufacture of tea, it forms the rolling tables, drying baskets, and sieves. The all-important chop-sticks are made of it. It is in universal demand in the house, on the water, in the field: the Chinaman is cradled in it at his birth, through life it is his constant companion in one shape or another, and in it he is carried to his last resting-place to repose even there under the shade of its long oval leaves." With this catalogue of the uses of the bamboo, we may dismiss the endogens.

Dicotyledonous or exogenous trees, which form the second class, are in much greater variety, and much more widely spread over the globe, than the trees of the first class. The form of their trunks is generally conical, tapering from the root to the summit: the summit or head of the tree is formed by the prolongation of the trunk, which divides into sundry primary branches; these again ramify into innumerable secondary branches; and these throw out small twigs, to which the leaves are attached by foot-stalks, larger or smaller. At first sight it appears as if the leaves grew by chance, but an order, regular and constant in each species, presides in their distribution.

On making a transverse section of a dicotyledonous tree, we see that it is composed of three parts, easily distinguished—the bark which envelops, the pith which forms the core or centre, and the woody substance which lies between the bark and the pith.

In the woody substance we distinguish two thicknesses: the one which envelops the pith is the greatest; and is

* *Radicle*, the conical body which forms one extremity of the embryo, and which, when germination takes place, becomes the descending axis or root of the plant.

† *Plumule*, the growing point of the embryo, situated at the apex of the radicle, and at the base of the cotyledons, by which it is protected when young. It is the rudiment of the future stem of a plant.

of a harder nature than that which adjoins the bark. The former is termed perfect wood, the latter *alburnum*. The inner layer of bark next the alburnum is called the *liber*, a name given from its being used to form the books (*libri*) of the ancients. Between the liber and the alburnum there is a substance partaking of the qualities of both, and called *cambium*. This is developed in the spring and autumn; when its internal portion changes insensibly into alburnum, and the exterior into liber. The liber never becomes wood: it is expanded continually by the process of growth in the tree, and forms the bark, which rends and exfoliates externally, because of its drying; and the layer of liber, in growing old, cannot extend in proportion to the augmentation in the circumference of the tree.

Duhamel and Buffon long since proved that alburnum, in process of time, became perfect wood; and there is now no doubt in regard to the manner in which the tree grows and produces its wood.

"Exogens, or outwood growers," says Dr. Lindley,* "are so called because, as long as they continue to grow they add new wood to the outside of that formed in the previous year; in which respect they differ essentially from endogens.

"In an exogen of ordinary structure, the embryo consists of a cellular mass, in which there is usually no trace of woody or vascular tissue; but as soon as germination commences, fine ligneous cords are seen proceeding from the cotyledons towards the radicle, meeting in the centre of the embryo, and forming a thread-like axis for the root. As the parts grow, the ligneous fibres are increased in thickness and number, and having been introduced among the cellular mass of the embryo, are separated from each other by a portion of the cellular substance, which continues to augment both in length and breadth as the woody cords extend. By degrees, the plumule or rudimentary stem becomes organized; and having lengthened a little, forms upon its surface one, two, or more true leaves, which gradually expand into thin plates of cellular substance, traversed by ligneous cords or veins, converging at the point of origin of the leaves. If at that time the interior of the young plant is again examined, it will be found that more ligneous cords have been added from the bases of the new leaves down to the cotyledons, where they have formed a junction with the first wood, and have served to thicken the woody matter developed upon the first growth. Those ligneous cords which proceed from the base of the leaves, do not unite in the centre of the new stem, there forming a solid axis, but pass down parallel with the outside, and leave a small space of cellular tissue in the middle; they themselves being collected into a hollow cylinder, and not uniting in the middle until they reach that point where the woody cords of the cotyledons meet in order to form the solid centre of the root. Subsequently, the stem goes on lengthening and forming new leaves: from each leaf may be again traced a formation of woody matter disposed concentrically as before, and uniting with that previously formed, a cylinder of cellular substance being always left in the middle. The solid woody centre of the root proceeds in its growth in a corresponding ratio, lengthening as the stem lengthens, and enlarging in diameter as the leaves unfold, and new woody matter is produced. The result of this is, that when the young exogen has arrived at the end of its first year's growth, it has a root with a solid woody axis, and a stem with a hollow woody axis, surrounding cellular tissue; the whole being covered with a cellular integument. But as the woody cords are merely plunged in a cellular basis, the latter passes between them in a radiating manner, connecting the centre with the circumference by straight passages, often imperceptible to the naked eye, but always present.

"Here we have the origin of pith in the central cellular tissue of the stem of wood in the woody axis, of bark in the cellular integument, and of medullary processes in the radiating passages of cellular tissue, connecting the centre with the circumference."

The woody axis is not, however, quite homogeneous at this time. That part which is near the centre contains vessels of different kinds, particularly dotted vessels (bothrenchyma): the part next the circumference is usually destitute of vessels, and consists of woody tissue exclusively: of these two parts, that with the vessels belongs to the wood properly so called, and serves as a mould about which future wood is added: the other belongs to the bark, separates under the form of liber, and in like manner serves as a mould within which future liber is disposed.

At the commencement of the second year's growth the liber separates spontaneously from the true wood; the viscid substance, cambium, is secreted between them; and the stem again lengthens, forming new leaves over its surface. The ligneous cords of the leaves are prolonged into the stem, passing down among the cambium, and adhering in part to the wood, and part to the liber of the previous year; the former again having vessels intermingled with them, the latter having none. The cellular tissue that connected the wood and the liber is softened by the cambium, and grows between them horizontally, while they grow perpendicularly, extending to make room for them; and, consequently, interposed between the woody cords of which they each consist; forming, in fact, a new set of medullary processes, terminating on the one hand in those of the first year's wood, and on the other in those of the first year's liber. The addition of new matter takes place equally in the stem and in the root, the latter extending and dividing at its points, and receiving the ends of the woody cords as they diverge from the main body.

The only respects in which the growth of exogens corresponds with that of endogens are, that in both classes the woody matter is connected with the leaves, and in both, a cellular substance is the foundation of the whole structure.

As new layers of alburnum are produced, they form concentric circles, which can be easily seen on cutting through the tree; and by the number of these circles one can determine the age of the tree. Some authors assert that this is not so, since a tree may produce in one year several concentric layers of alburnum, and in another year only one. Nevertheless, the commonly received opinion is, that the number of concentric circles in the cross section of the wood, called annual layers, indicates the time it has taken to reach its size. Although a layer of alburnum is deposited each year, the process of transformation

* *Vegetable Kingdom*, p. 235.

of it into perfect wood, otherwise *heart-wood*, is slow, and, consequently, the alburnum, or *sap-wood*, comprehends many annual layers.

The annual layers become more dense as the tree grows aged; and when there is a great number in a tree of small diameter, the wood is heavy, and generally hard also. In wood which is either remarkably hard or remarkably soft, the annual layers can scarcely be distinguished. They cannot, for example, be distinguished in ebony, and other tropical woods, nor in the poplar, and other soft white woods of our climate. In the case of the softer woods in our climate, the layers are frequently thinner and more dense on the northern side than on the opposite. In a transverse section of a box tree, about 7 inches diameter, we reckoned 140 annual layers.

The roots of a tree, although buried in the soil, have, as we have seen, an organization resembling that of the trunk and branches. The roots of several trees are employed in the arts, but as none of them are used in carpentry we need not dilate on the subject: we shall only remark, that as the branches of a tree divide into smaller branches and twigs, expanding to form a head, so the roots divide also into branches, which expand in every direction in the ground, and these branches again divide, their ultimate division being into filaments, commonly called fibres, which appear to be to the roots what the leaves are to the branches.

It has been remarked that there is a sympathy between the branches and the roots in their development. Thus, when several considerable branches of a tree are lopped off, the corresponding roots suffer, and often perish.

CULTIVATION OF TREES.

Trees are the produce of forests, planted spontaneously, and consequently very ancient, or of forests and plantations created by man since he has engaged in this kind of culture.

The reproduction of trees, their culture, and the felling of timber, belong more to the management of forests than to the art of carpentry; but we shall remark briefly on some qualities which are derived from growth.

The size and fine growth of a tree is not an infallible sign of goodness of quality in the wood. The connection of the age of a tree with its development, and the nature of the soil in which it grew, ought to be inquired into to enable a judgment to be formed of the quality of the wood.

In general, boggy or swampy grounds bear only trees of which the wood is free and spongy, compared with the wood of trees of the same species grown in good soil at greater elevations. The water, too abundant in low lying argillaceous land, where the roots are nearly always drowned, does not give to the natural juices of the tree the qualities essential to the production of good wood. Trees grown in such places are better adapted for other works than those of the carpenter. The oak, for example, raised in a humid soil, is more proper for the works of the cabinet-maker than for those of the carpenter; because it is less strong and stiff, and is softer and more easy to work than the same wood raised in a dry soil and elevated situation: it is also less liable to cleave and split when only employed for small works. Its strength, compared with that raised in a drier soil is about as 4 to 5, and its specific gravity as 5 to 7.

Wet lands are only proper for alders, poplars, and willows. Several other species incline to land which is moist or wholly wet; but the oak, the chestnut, the elm, thrive only in dry situations, where the soil is good, and where the water does not stagnate after rain, but is retained only in sufficient quantity to enable the ground to furnish aliment for the vegetation. Resinous trees, too, do not always thrive in the soils and situations proper to the other kinds of timber, and especially in marshy soils: sandy soils are in general the best for their production; and several species affect the neighbourhood of the sea, such as the maritime pine, not less useful for its resin than for its timber.

In fine, trees which grow in poor and stony soils, and generally in all such soils as oppose the spreading of their roots, and do not furnish a supply of their proper sap, are slow and stunted in their growth, and produce wood often knotty and difficult to work, and which is mostly used as veneers for ornamenting furniture.

The surest tokens of good wood are the beauty, clearness, and firmness of the bark, and the small quantity of alburnum.

It has been remarked that timber on the margin of a wood is larger, more healthy, and of better quality than that which grows in the interior, the effect of the action of the sun and air being less obstructed.

DISEASES OF TREES.

Trees, like animals, are subject to disease. When, by the effect of old age or disease, a tree dies at the bottom, even before it has arrived at the ordinary limit of existence of individuals of the same species, its wood loses the qualities not only essential for timber construction, but also for combustion. It loses flexibility, strength, and durability; it becomes dry and soft; when it falls it rapidly rots, or becomes the prey of worms; and it burns without flame, and with little heat. If, in place of this, it is felled in its vigour, it ceases to live, it is true; it no more vegetates, it becomes dry, but it preserves all its useful qualities, and is fit for any of the purposes to which timber can be applied. Diseases of plants are, for the most part, dependent on chemical changes in their component parts.

The maladies which arise from outward causes are sores, mutilations, and fractures, which may be the result of the action on the bark of the teeth of large animals, of strokes given by accident or design, the effects of wind, or of lightning. This latter agent is the most destructive: the trees are shivered partly by mechanical agency, partly by sudden expansion of gas.

Dr. Colin observed that the electric fluid first takes the course of the alburnum as the best conductor, splitting off the bark by the sudden expansion of the fluid; a part enters the older portions of the wood, which are comparatively bad conductors, taking the course of the medullary rays, or points of conduct of the annual layers, or both; and thus splits the tree in various directions, occasionally threading it to the extremity of the roots.

The maladies which can arise from accidents, and from the customary regimen of vegetation, or from the state of the atmosphere, and from meteors, are:—Ulcers, cankers, rottenness, chaps, clefts, and other diseases caused by frost and cold, exfoliations, tumours, knobs, warts, excrescences, plethora, return.

Ulcers and *Cankers* in trees resemble the same diseases in animals. The origin is generally in the roots. A too great abundance of sap in some part of a tree manifests itself in a kind of external suppuration, which is accompanied by a corruption of the fluids, and speedily of the wood adjoining the ulcerated part. The disease sometimes spreads, causes the bark to peel off, and then the tree perishes. Ulcers in elms are due to a collection of corrupt fluid from the decomposition of water or sap percolated through decayed tissue. The fluid blackens whatever it touches, and is extremely fœtid: when a tree so infected is felled, the odour is very disagreeable while the infected parts are being lopped off.

Rottenness proves the existence of some disease in the sap. In this disease, the woody fibre is reduced to powder.

Ulcers, cankers, and rottenness also proceed from water obtaining access to the interior of a tree at the points where the branches leave the trunk,—through clefts, which are generally produced by unwonted straining of the branches by the wind.

Chaps in the bark are occasioned by scorching winds, drought, sudden changes of season from cold to heat, or *vice versâ;* or from the too violent action of the sun. These expose the wood of the tree to the action of the weather; and their existence is the sign of deterioration in the wood.

Circular Chaps, surrounded by other chaps in rays, are supposed to be caused by some insect.

Frost Cracks commence in the bark, penetrate the new wood, and sometimes extend deeply into the heart-wood. They are caused by the freezing of the water of the sap, which splits, first the bark, and then the wood of the tree.

Rigorous frosts sometimes act upon the external layers of alburnum, and hinder them from passing into perfect wood, although they continue to exercise their functions in the transmission of the materials which form the new layers, but in such manner that these do not adhere to the layers of the year previous. When these arrive at the state of perfect wood, a void, extending over a considerable portion of the trunk, and sometimes throughout its circumference, is left between them and the layers injured by the frost. Two concentric cylinders are thus formed, detached, and separated sometimes by an interval of a finger's breadth.

Twisted Fibres are not the result of disease, but of deformity caused by the prevalent action of the wind in one direction on the head of the tree. The stem, when young and tender, is thus twisted, and its fibres retain their screw form when they pass into perfect wood. Twisted wood is not proper for the use of the carpenter, as in squaring it many of its fibres would be cut through.

Exfoliation.—This is a disease of the bark, in which it detaches itself in layers. There results from this an alteration in the alburnum, and in the wood which it furnishes. It is believed that exfoliation is caused by some insect, which as yet, however, has escaped microscopical research.

Tumours, Warts, Excrescences, and *Abscesses,* all proceed from local disease, which produces deterioration of the alburnum, and an excessive affluence of sap at certain points; resulting in extravasation and accumulation of vegetable substance, forming excrescences and confused contexture. They are often, too, caused by wounds, by the attacks of insects, and by parasitical plants. They injure the wood by disturbing the uniformity of the ligneous fibre.

Plethora.—This is the result of an over-abundance of nutritive juices, drawn irregularly to different parts of the tree, and causing deformity. The quality of the wood is consequently injured by the impairing of its homogeneousness; and its strength could not be trusted, especially if exposed to transverse strains.

Return.—This is the last disease of growing trees which have passed the term of their maturity. It commences at the top of the head; and whether it is owing to the obstruction of the channels which convey nourishment, a deficiency of the nourishment itself, or weakened vital energy, its symptoms are a drying and decay of the top shoots, then of the branches, and lastly of the trunk itself. On the first appearance of the symptoms the tree should be felled, in order to save the timber.

TIMBERS FIT FOR THE CARPENTER.

In general, regularity in the roundness, and the taper, of a tree, and a fine or uniform texture in the bark, indicate it to be of good quality.

All appearance of knots, wens, swellings, old sores, although cicatrized, all traces of canker, or of water having reached the heart of the tree, are infallible signs of diseased wood. Fresh mosses and lichens on a tree which has been some time felled, are symptomatic of its having lain in a wet place. These may also indicate the locality of some internal disease.

It requires a practised eye to judge of the qualities of timber while yet in the unbarked tree; but, as the carpenter generally receives the wood on which he operates, squared, this knowledge is not of so much importance to him as it is to the timber-merchant.

The qualities which fit wood for works of carpentry are durability, uniformity of substance, straightness of fibre, and elasticity. When wood is squared, its good quality, especially in the case of the oak, the chestnut, and the elm, is known by a fresh and agreeable odour which it exhales, and which is very different from the smell of wood, however freshly cut, which has begun to decay. When timber has been felled for a long time, and has become dry, this peculiar odour is not so perceptible, but the resinous trees retain the smell of the resin for a very long time; the odour being again made perceptible by cutting a slice from the surface. Dry and healthy timber is solid, tenacious, sonorous, and elastic; when it is dead or diseased, it is soft, emits a dull sound when struck, and acquires a disagreeable smell.

The good quality of wood is known also by the uniformity and depth of the colour peculiar to its species. When the colour varies much from the heart to the circumference, and, above all, when it lightens suddenly or too rapidly towards the limit of the alburnum, we may be assured that the tree is affected by some disease.

The white wood or alburnum of trees should be rejected; and where there is a double layer of white wood, separated by a layer of perfect wood, as is sometimes though rarely the case, the wood is unfit for use.

Knotty and cross-grained wood is difficult to work. Cross-grained wood is rarely of great dimensions, and is employed chiefly in the construction of machines, and for purposes in which the tenacity of its fibres is its recommendation. It is rejected for ordinary work, because it is difficult, and, consequently, expensive to work, and weighs heavy in proportion to its strength. Such timber is very often, however, employed in hydraulic works, especially when it is to be wholly under water. It is apt to become shaky diagonally in drying.

A great defect is when the fibres do not approach to equality of size. Perfect equality is impossible in tapering timber, but such an equality as shall not render one part of the piece of timber much less strong than another is obtainable by proper selection.

In knotty wood, the knots interrupt that straightness of the fibres which gives strength. The knots are the prolongations of the branches across the perfect wood of the tree from the points where the branches have commenced. Such knots augment in size in the degree that the trunk of the tree increases. If the branches have grown with the tree to the time of its being felled, the knots will be perfect wood, the fibres of the trunk will only be turned slightly from their straightness, and if the knots are few they will not be very hurtful. But if the branch forming the knot has been suppressed or destroyed, or has by any cause ceased growing while the tree grew, the knot formed by it will be inclosed in the new layers of wood, and may become a cause of destruction by the decaying of its substance from contained moisture, and thus a nidus of rottenness is formed within the tree. It is therefore prudent to probe such knots, and, if they are decayed, to cut off all the wood which is traversed by them. In general, the prevalence of knots in a piece of wood indicates that it has been cut from a branch and not from the trunk of a tree.

Wood which in growing has been blighted by frost is not fit for the carpenter. The lateral cohesion of its fibres is destroyed, and it contains numerous little chaps which absorb moisture and cause it to rot.

When timber in growing has been subjected to strong frosts and thaws, the wood is often alternately alive and dead, and filled with small clefts. It is recognized by an appearance of marbling which it presents on being cut.

Krafft, in the introduction to his *Carpentry*, has the following remarks:—"It is important," he says, "in the employment of timber, in pieces used vertically, to place them with the butt on high, and the top downwards. To know if a piece of timber is sound in the middle, saw its two ends, then cause blows with a hammer to be struck at one end, while the ear is placed against the other; and if the sound is dull the timber is bad; but if, on the contrary, it is clear, the timber is good."

Generally when the tree is sound the density decreases from the butt upwards, and from the centre to the circumference. The greatest strength is found between the centre of the tree and the sap-wood; and the heaviest wood is the strongest.

Sound wood under the saw cuts clean, is bright in colour, and, when planed, has a silky lustre: unsound timber wants this lustre, and the saw leaves a woolly surface.

FELLING OF TIMBER.

In the clearing of a forest, where all the trees without distinction are felled, the work of destruction commences at the borders nearest the roads which bound or traverse it, and proceeds with order and regularity. Care is taken not to embarrass the outlets, or obstruct the roads. The manner of procedure is according to the end proposed. If that be the destruction of the forest and the freeing of the soil from the remains of trees, in order that it may be appropriated to some other species of culture, the trees are removed by the roots, care being taken, in the case of certain species tenacious of life, not to leave any shoot, however small. If, again, the object be to produce copse, the trunks of the trees are cut close to the ground, that the stumps left in the soil may throw out new shoots.

In thinning a forest, such trees only are felled as have attained the limit of their development of growth, or at least as have acquired the qualities which fit them for the purposes sought.

The felling of timber is performed in either of the three following ways:—

1. The tree is felled with its trunk and stump separated from its roots.
2. It is torn up with all its roots attached.
3. It is cut above the soil, either by the saw or by the axe, with the intention of removing the stump afterwards, or leaving it for the production of new wood.

In practising the first method, the earth is removed from around the tree to the depth which will admit of the roots being cut through; but is retained to fill up the excavation. The roots are then hewn or sawn through, and by means of ropes the tree is pulled over to the side where its fall will least injure the neighbouring trees, or obstruct the operations on them. The roots are then dug out, and the earth is thrown back into the hole made by the removal of the stump.

In the case of such trees as have a stump penetrating deeply into the ground, the earth may be removed from around the stump to such a depth only as will admit of the lateral roots being cut through. The tree is then retained in its vertical position by a pivot merely; and by means of chains and levers properly applied, the resistance of this is overcome, and the tree thrown down as before. This mode cannot be practised in the case of trees which throw their roots vertically downwards, such as the chestnut, the elm, &c. To remove a tree with all its roots attached, the method is as follows:—The earth is removed from the principal roots, so as to admit of cords being passed under them. Then, by means of levers the roots are raised one after the other; cords or chains are next passed under the stool, which is raised in the same manner; and the tree is guided in the direction in which it is wished it should fall.

Sometimes the tree is overturned by the aid of gunpowder. To effect this, it is necessary to remove the earth from around the roots, so as to diminish the resistance of the soil. Then, under the trunk a small metal mortar with a large base is posited upon a piece of wood which

is still larger. The loaded mortar is covered with a cast-iron plate having portions of its corners cut off, so that the force of the explosive gases may be directed against the tree. This method is very little used.

The third mode of felling is the most generally adopted. It is the only available method in the case of such trees as do not throw out branches at the foot, when it is wished to leave a stool for the reproduction of wood. The wood-cutter makes at the foot of the tree an incision with his axe, cutting deeper at the side on which he wishes the tree to fall. The cuts should nearly meet at the centre; for if too large a solid pivot be left, the falling of the tree would tear it out of the stool, and make a hole there, which would cause decay, and unfit the stool for reproduction.

When a tree is felled by the axe, it should be cut as close to the ground as possible, to get the largest amount of trunk timber. This is, moreover, serviceable, as increasing the quality and beauty of the new wood which the stool throws out. The top of the stool, for obvious reasons, should be slightly convex or pyramidal.

But it is more economical to cut the tree by the saw than by the axe. Ordinarily, facilities are afforded to the workmen in applying the instrument, by sinking a pit on each side, in which they can stand. As the saw makes way, the weight of the tree would render it impossible to work it: this is remedied by inserting small wedges in the saw-kerf, so that the blade may work freely.

Many modifications of saws for the cutting of growing timber have been from time to time invented, and also machinery for giving motion to both circular and reciprocating saws.

It has been observed that the costs of the three methods described bear the following relation. Tearing up by the roots costs twelve times as much as felling by the axe; while the method in which the horizontal roots are cut off and the tree pulled over, costs only twice as much. But by both these methods, the available timber is increased to an extent which more than compensates for the additional cost.

When, for culture of the soil, the removal of the stump is desired, either of the two first methods of felling is more advantageous than the last, from the effective leverage which the falling tree exerts.

The proper season for the felling of timber has often been debated.

In Italy and in Spain, timber is felled in summer, and is found, nevertheless, to be very durable. But it would be improper to draw a rule from the practice in countries where the heat and the dryness of the atmosphere favour the rapid dissipation of the natural juices of the tree. Some authors argue that the tree should be felled at the time of the year when the development of the vegetation is at its height. Others contend that the proper season is when vegetation has ceased. Tradition, which, in matters of this kind, submitted to the test of daily experience, is seldom wrong, favours altogether the latter view; and the rule has been to cut the tree between the fall of the leaf in autumn and the rise of the sap in spring—vegetation being then inert.

Buffon and Duhamel advocated the practice of stripping the bark from the tree a year before felling, on the supposition that the alburnum by this exposure became perfect wood. The supposition, it need scarcely be said, is wholly erroneous; and a grave evil attending the practice is, that this depriving the tree of its bark while it is yet growing, causes it to die, and injures the elasticity of the timber.

To diminish the quantity of sap in the tree before felling it, some have recommended an incision to be made all round the tree immediately above the ground, and so deep as to leave a solid pivot merely large enough to sustain it. This is termed girdling. The connection between the roots and the trunk and its leaves being thus dissevered, it is supposed that the sap escapes more freely. The practice does not obtain—for these reasons; it is expensive, it is not known to be beneficial, and it is dangerous in the event of high winds. The rapid exhaustion of the sap could be obtained by placing the tree vertically after it is cut; but the cost of doing so would be very great.

SQUARING OF TIMBER.

In order to fit the cylindrical stem of a tree for the ordinary purposes of the carpenter, it is reduced to the form of a rectangular prism—a form the most convenient, whether the purpose be the connection of the pieces of timber by uniting them together either in length or in thickness, or in any of the diverse ways which ordinary carpentering requires. It may be said that all the wood delivered to the carpenter to be operated on, with the exception of what is intended for pillars, piles, or posts, requires to be squared.

In squaring a tree, the object to be aimed at is to obtain either as large a parallelopipedon as possible, or one which has its dimensions suited to the purpose for which it is to be employed.

The operation of squaring is generally performed by the woodmen who fell the timber; and who, by long experience, can judge at a glance what kind of squared timber a tree, however deformed, will yield.

The carpenters thus, in general, have little to do with the squaring of the timber, especially that of foreign growth; but in works in which it is necessary to employ timber the produce of our own country, the tree is often selected and purchased while growing, and is not reduced to the square form until it comes to the hands of the carpenter. The operation may be thus shortly described:—

The tree being elevated on tressels, transverse sections are made with the saw at both ends perpendicular to its axis, and on the perfect wood thus exposed, the rectangle forming the base of the parallelopipedon is inscribed.*

* It may be shown that the largest rectangle which can be inscribed in the circle is a square. For if, in Fig. 415, we divide

Fig. 415

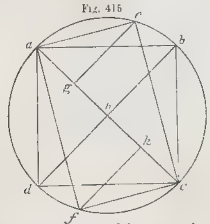
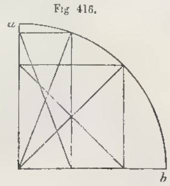


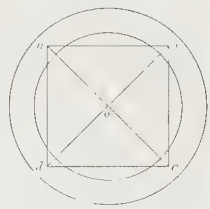
Fig. 416.



the square $a\ b\ c\ d$ into two isosceles triangles $a\ b\ c$, $c\ d\ a$, inscribed in the two semi-circumferences which compose the circle, each of

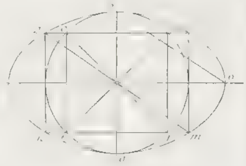
Let the outer circle in Fig. 417 represent the smaller end of the tree; and let the inner circle distinguish the separation between the heart-wood and sap-wood. The rectangle of the greatest square will be obtained by inscribing the square *a b c d* in a circle which passes this a little. The centre *o* of this latter circle is easily found geometrically. Through this centre, two lines are drawn at right angles to each other, and from it are set off along these lines the four equal distances *o a*, *o b*, *o c*, *o d*, extending a little way beyond the line of the true wood; and *a b c d* give the arrises of the squared timber.

Fig. 417.



When the tree is elliptical, however, a square is not the greatest rectangle that can be obtained, and it is necessary to proceed as follows:—On the minor axis *a b* of the ellipse (Fig. 418) describe a circle, and inscribe therein a square *c d e f*, and produce the sides *c d*, *f e* to *g h*, *k m*; then will *g h k m* be the largest rectangle that can be inscribed in the ellipse. In practice, having drawn the two axes of the ellipse, draw the chord line *b o*, and through the centre draw *g m* parallel therewith; then from *g* and *m*, where this line intersects the line of separation between the alburnum and perfect wood, draw *g h*, *k m* parallel to the major axis, and *g k*, *h m* parallel to the minor axis, and the rectangle will be obtained.

Fig. 418.



But it rarely happens that trees are so regular in their form as to admit of such rules being applied. In ordinary cases where the deformity is not great, the application of the callipers to the end will enable the operator to discover the greatest squaring dimensions of the tree. In some cases the deformity is so great that the only guide is practice and a good judgment.

MANAGEMENT OF TIMBER AFTER IT IS CUT.

The management of cut timber, so as to preserve its qualities from deterioration, and gradually to fit it for the purpose to which it is to be applied, is a subject of great importance.

If timber be exposed to great changes of temperature, to alternations of wetness and drought, to a humid and hot atmosphere, it will inevitably suffer a deterioration of those qualities which render it serviceable for the carpenter.

Timber, when too suddenly dried, is liable to split: when exposed to too high a temperature in a close atmosphere, its juices are liable to fermentation, followed by a loss of tenacity and a tendency to rot and become worm-eaten. The greater the quantity of timber thus kept together, the more rapidly is it impaired, which is made sensible to the smell by a peculiar odour emitted from it.

When timber is exposed to injury from the weather, and lying long exposed on a damp soil, it is attacked by wet rot. The alternations, too, of drought and rain, of frosts and of heat, disorganize the woody fibre, which breaks, and a species of rottenness ensues resembling the decay of growing timber. The means of defending the timber from these various causes of waste, and preserving it in a state fit and proper to be used in construction, we now propose to describe.

Although the carpenter has not often to undertake the charge of the timber in the place of its growth, yet as there are cases in which he is called upon to do so, we shall begin by describing the means of preserving the tree from the time it is felled to the period when it is to be used in construction.

When the tree is felled, it should be preserved from contact with the soil, by being elevated on short pieces; and to prevent its too rapid desiccation, and the consequent formation of clefts and shakes, it should be sheltered from the sun, but so as to permit a free circulation of air around it. Where the felling of wood is performed on a large scale, sheds, which may be opened on any side at pleasure, should be constructed, in which the trees may be deposited. In these, the trees, defended from the sun and rain, may be exposed to the air, but with the power of controlling and modifying its action. It has been observed, that in sheds open on all sides the timber decays and splits more rapidly than in the open air.

In piling the timber in these sheds, the trees should not be allowed to be in contact, but should be separated by pieces formed of a quarter section of a tree. They should also be carefully classed according to diameter, in order that the different trunks may be kept level, and each have a solid bearing, to prevent its sagging, and becoming curved. The longest trees should of course be placed undermost.

When the timber is squared and cut up, even greater care must be bestowed on it; not alone on the ground that it is then so much the more valuable by the labour which it has cost, but because, by its vessels being divided, it is more easily affected by deteriorating causes; and by its surface being augmented, these causes have also a larger field to operate on.

Timber of the same scantling, felled and cut up at the same time, should be piled together; and there should not be mingled in one pile wood of different species.

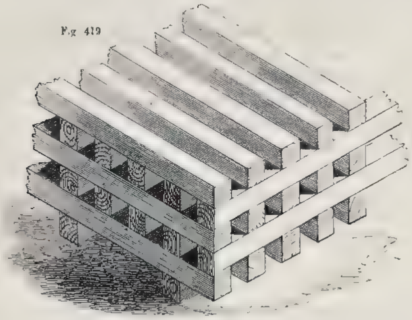
The first layer of the pile (Fig. 419) should be elevated above the soil on sleepers, the higher the better, as securing a freer circulation of air, and preventing the growth of fungi. The most perfect security, however, is obtained by paving the site of the pile, and building dwarf walls or piers, with strong girders, to form the foundation for the first tier.

Where the space will admit of it, and the timbers are square, they should be laid in tiers crossing each other alternately at right angles, and at least their own width

these triangles is greater than any other triangle *a e c*, *a f c*, moieties of any rectangle *a e c f* whatever, inscribed in the same circle; because both sets of triangles having the same base, *a c*, the altitudes *h b*, *h d* of the first triangles are greater than the altitudes *g e*, *k f* of the second triangles; and therefore the square *a b c d*, the sum of the two triangles *a b c*, *c d a*, is greater than the rectangle *a e c f*, the sum of the two triangles *a e c*, *c f a*. In the same manner it may be demonstrated that the square is the greatest rectangle that can be formed in the quadrant *a b* (Fig. 416).

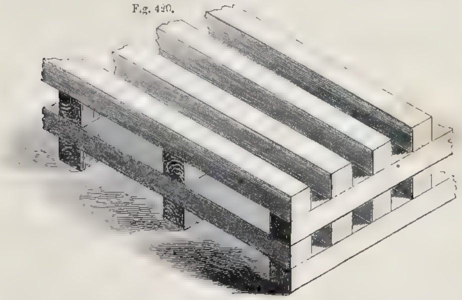
apart. This method will not do for thin planks, because it would not allow a sufficient circulation of air. These

Fig. 419.



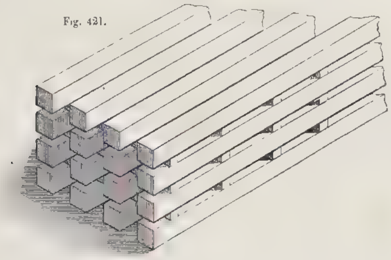
are better when piled so that in the alternate tiers there are only planks sufficient to keep the other tiers from bending. Where space can be afforded, it is well to pile square timber in this way. The diagram (Fig. 420) will best explain this mode. Where space for this cross piling

Fig. 420.



cannot be afforded, pieces must be inserted between the tiers, as shown in Fig. 421.

Fig. 421.



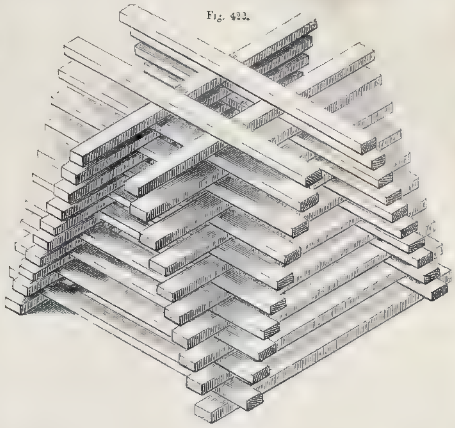
Sometimes it is convenient to pile the wood vertically against a wall, selecting a northern aspect, and sheltering the timber by a pent-house roof.

It is profitable to move the wood from the piles and replace it, turning the sides, altering the relative positions of the different pieces in the pile, and changing the points of support; and at the same time picking out and excluding any damaged or deteriorated piece. The pieces between the different tiers should at the same time be interchanged; and before being used again, they should be carefully inspected, and, if decayed or diseased, rejected.

Every vestige of bark should be removed from the wood before it is piled; for the bark often contains the germs of disease, or is infested with insects, and in either case injury is done to the pile.

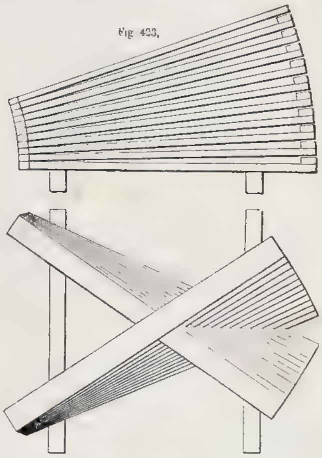
When the timber has been accidentally wetted, or when it is necessary to hasten its desiccation, it should be set

Fig. 422.



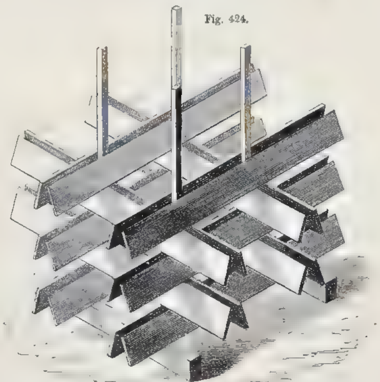
up against a wall or formed into a hollow pile, as shown

Fig. 423.



in Fig. 422. Another way is by crossing the planks, as seen in Fig. 423; and another, which admits the pile

Fig. 424.



being carried to a greater height, is by erecting four posts and building the timber about them, as seen in Fig. 424

OF THE BENDING OF TIMBER.

Curved forms, either essential to the stability of a structure, or necessary for its decoration, require that the carpenter should obtain the timber naturally curved, or should possess the power of bending it. Trees which yield timber naturally curved, are generally used for the constructions of the naval architect. If, in civil constructions, where curved timber is required, it should be attempted to be formed by hewing it out of straight timber, two evils would ensue: the first, a loss of wood; the second, and greater, the destruction of its strength by the necessary cross-cutting of its fibres. Hence, to maintain the fibres parallel among themselves, and to the curve, recourse is had to curving or bending the timber artificially. This process may be performed on the trees while yet growing, or on the timber after it is squared or cut up. The first process is rarely performed, and need not be here described in detail. We shall therefore proceed to the consideration of the second.

The process of bending timber artificially is founded on the property which water and heat have of penetrating into the woody substance, rendering it supple and soft, and fitting it to receive forms which it retains after cooling.

This process is extremely ancient. A familiar illustration of the power of the simultaneous action of heat and moisture in altering the form and dimensions of wood, is the well-known little puzzle of a key sliding in a mortise: the key is in one piece, and its two ends have projections which make their thickness twice that of the part which slides in the mortise; and the wonder is, how, under these circumstances, it was possible to insert the key; and being inserted, how to remove it. The difficulty is overcome by steeping one of the ends in boiling water till thoroughly penetrated, and then squeezing it in a vice till its dimensions are reduced, so that it passes through the mortise: when the wood dries and cools, it resumes its original bulk and form. The softening preparation for bending timber is effected in the five following ways:—

1. By using the heat of a naked fire.
2. By the softening influence of boiling water.
3. By softening it by vapour.
4. By softening it in heated sand.
5. By vapour under high-pressure.

Of the first method of operation, a familiar example is afforded by the cooper, who bends the staves of his casks by kindling within the vessel formed of straight staves, a fire of straw or shavings. It is also used in bending the planks used in ship-building; but it is, on the whole, only applicable to timbers of small scantling; and in such cases as occur seldom, and where one or two pieces only are required to be bent.

In the second method, the timber is immersed in water, which is heated until it boils, and is kept boiling until the timber is wholly saturated and softened. The timber being then withdrawn, is immediately forced to assume the required curvature, and is secured by nails or bolts. This proceeding has the defect of weakening the timber, and lessening its durability. It should, therefore, be used only in such cases as do not require the qualities of strength and durability.

In the third process, the timber is submitted to the action of the steam of boiling water. For this purpose it is inclosed in a box made perfectly air-tight. The box has a series of grated horizontal partitions or shelves on which the timbers are laid. From a steam boiler conveniently situated, a pipe is carried to the box. The steam acts on the timber, and in time softens it and renders it pliant. The time allowed for the action of the steam to produce this effect, is generally one hour for every inch of thickness in the planks.

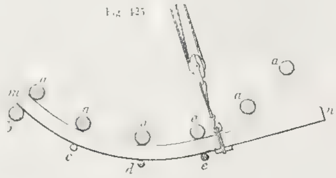
The fourth method of preparing the wood for bending, is by applying heat and moisture to it through the medium of the sand bath. The apparatus for this purpose is a furnace with flues, traversing the stone on which the sand is laid, in the manner of hot-house flues. There is also provided a boiler in which water is heated. On the stone a couch of sand is laid: in this the timbers are immersed, being set edgeways on a bed of sand about 6 inches thick, and having a layer of sand of the same thickness separating them, and being also covered over with sand. The fire is then lighted in the furnace, and after a time, the sand is thoroughly moistened with boiling water from the boiler before mentioned. This watering is kept up all the time that the timber is in the stove. Thin deals require, as in the preceding case, an hour for each inch of thickness; but for thick scantlings the time requires to be increased; for instance, a 6-inch timber should remain in the stove eight hours.

The fifth mode, by means of high-pressure steam, only differs from the third process described in this, that the apparatus requires to be more perfect. The box, therefore, is generally made of cast-iron, and all its parts are strengthened to resist the pressure to be employed. When the steam has a pressure of several atmospheres, the softening of the wood is very rapid; and it is very effectually done by this method.

After the timber is properly softened and rendered pliable, it is bent on a mould having a contour of the form which the timber is required to assume.

The simplest method of doing this is shown in outline in Fig. 425. A series of stout posts, *a a a*, are driven

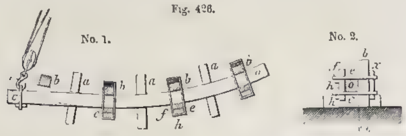
Fig. 425.



into the ground, on a line representing the desired curve. The piece of wood *m n*, when softened, is inserted between two posts at the point where the curvature is to begin, as at *a b*, and by means of a tackle, applied near that point, it is brought up to the next post, *a*, where it is fixed by driving a picket, *c*, on the opposite side. The tackle is shifted successively from point to point; and the pickets, *c*, *d*, *e*, are driven in as the timber is brought up to the posts. It is left in this condition until it is cold and dried; and then it is removed to make

way for another piece. The timbers of the roof, *Fig.* 3, Plate XXIX., were bent somewhat in this manner. But if the balk is required to be more accurately bent, and out of winding in its breadth, squared sleepers, *a a a* (Fig. 426, Nos. 1 and 2) are laid truly level across the line of curvature, and the posts *b b* are also accurately squared on the side next the balk. An iron strap *c*, which is

Fig. 426.



made to slide freely, is used for attaching the tackle, and as the balk is brought up to the curve, it is secured to the posts *b*, *b* by two iron straps, *e e*, *e e* (seen better in the vertical section, No. 2), which embrace the pieces *f*, on the opposite side, and are wedged up tight by the wedges *h h*.

In operating in either of the ways described, only one piece of timber can be bent at a time. By the following method several pieces may be bent together:—

Fig. 427 is a vertical projection, and Fig. 428 a transverse vertical section, of the apparatus. It consists of the horizontal pieces *a a*, arranged with their upper surface in the contour of the curve. They are sustained by strong framing *b b*, *c c*, *d d*. The timber is laid with its centre on the middle of the frame, and by means of purchases applied at both sides of the centre, and carried successively along to different points towards each end, it is curved, and secured by iron straps and wedges as before. The frame may be made wide enough to serve for the bending of other pieces, as *m*, *n*; or for a greater number, by increasing the length of the pieces *a a*, and supporting them properly. The two apparatuses last described are taken from Colonel Emy's work.

Fig. 427.

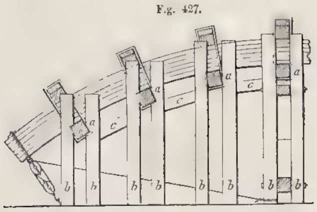
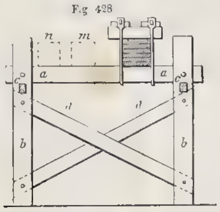


Fig. 428.



These methods are not quite perfect; for in place of the timber assuming a regular curvature, it will obviously be rather a portion of a polygonal contour. To insure perfect regularity in the curve, it is necessary to make a continuous template, in place of the several pieces *a a a a*. The substitution of the template for these, we need not, however, illustrate or describe, as its construction will be suggested by what has already been said.

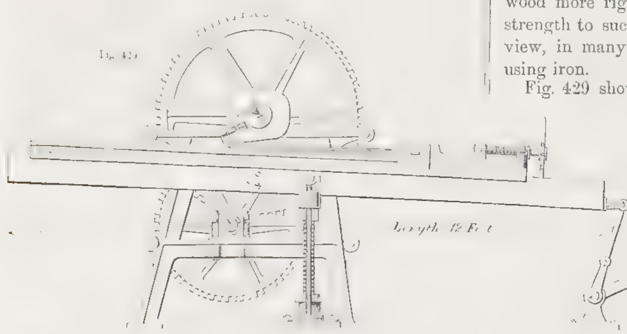
It is necessary to remark, that in all the cases, the timber should be preserved from being injured by the iron strap, by a piece of wood inserted between them, as shown in the figures.

Care must be taken that the curvature given to the timber is such as will not too greatly extend, and, perhaps, rupture the fibres of the convex side, and so render it useless.

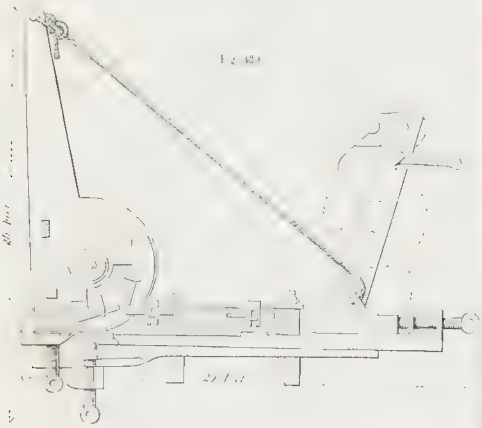
The process of bending timber which we have described, is, as will be seen, restricted to very narrow limits. The effect, when the curve is small, is to cripple the fibres of the inner circumference, and to extend those of the exterior, and the result is, of course, a weakening of the timber. Recently, however, a process has been patented by an American gentleman, Mr. T. Blanchard, in which the bending, effected by end pressure, is not only not attended with injurious effects, but on the contrary, gives to the timber qualities which it did not before possess. In an able article in *Household Words*, the advantages of this new process are set forth as follows:—"The principle of bending, as employed in this new application, is based on end-pressure, which, in condensing and turning at the same time, destroys the capillary tubes by forcing them into each other. These tubes are only of use when the tree is growing, and their amalgamation increases the density of the timber, the pressure being so nicely adjusted that the wood is neither flattened nor spread; nor is the outer circumference of the wood expanded, though the inner is contracted. Now, the error of the former process, as expounded by competent judges, has arisen from the disintegrating of the fibre of the wood by expanding the whole mass over a rigid mould. Wood can be more easily compressed than expanded; therefore, it is plain that a process which induces a greater closeness in the component parts of the piece under operation—which, as it were, locks up the whole mass by knitting the fibres together—must augment the degree of hardness and power of resistance. The wood thus becomes almost impervious to damp, and to the depredations of insects, while its increased density renders it less liable to take fire; and the present method of cutting and shaping timber being superseded, a saving of from two to three fourths of the material is brought about. The action of the machine throws the cross grains into right angles, the knots are compelled to follow the impulse of the bending, the juices are forced out of the cells of the wood, and the cavities are filled up by the interlacing fibres. In the same way, you may sometimes see in the iron of which the barrels of muskets are made, a kind of dark grain, which indicates that the particles of the metal, either in the natural formation or in welding, have been strongly clenched in one another. These specimens are always valued for their extraordinary toughness, as well as for a certain fantastical and mottled beauty.

"Another of the good results of this method is, that the wood is seasoned by the same process as affects the bending. The seasoning of wood is simply the drying of the juices and the reduction of the mass to the minimum size before it is employed, so that there should be no future warping. But, as we have already shown, the compression resorted to in the American system at once expels the sap, and a few hours are sufficient to convert green timber into thoroughly seasoned wood. Here is an obvious saving of time, and also of money; for the ordinary mode of seasoning by causing the wood to lie waste for a considerable period, locks up the capital of the trader, and of course enhances the price to the purchaser. Time also will be saved in another way, in searching for pieces of wood of the proper curves for carrying out certain

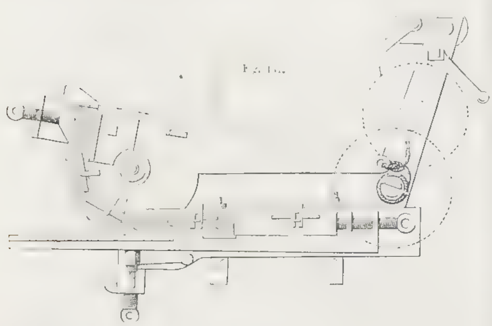
designs. 'How delighted,' says Mr. Jervis, the United States inspector of timber, 'will the shipwright be to get clear of the necessity of searching for crooked pieces of timber; there need be no longer any breaking of hats in the frame, as we have been wont to break them. We shall see Nos. 1, 2, and 3 futtocks, at least, all in one piece.' An English architect, Mr. Mayhew, remarks that 'one of the advantages of this method is, that in its



application to all circular, wreathed, or twisted work, it not only preserves the continuous grain of the wood, which



is now usually and laboriously done by narrow slips of veneers glued on cores cut across the grain, with many

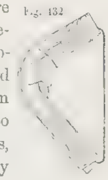


unsightly joints, ill concealed at best, but it will materially reduce the cost of all carved work, which now varies according to the quickness of the sweep, and will give the artist greater freedom in his designs, by allowing him to introduce lines which are now cautiously avoided, in order to prevent the cost of their execution.'"

Mr. Mayhew further observes, that the process has the capability of bending into a permanently set form any wood up to 16 inches square, however hard, not only without injuring its fibres, but positively rendering the wood more rigid, and, at the same time, increasing its strength to such an extent, that in a structural point of view, in many cases, it will supersede the necessity of using iron.

Fig. 429 shows the form of the machine for timbers under 6 inches square. Figs. 430 and 431 show the machine for heavy timbers above that scantling.

The principle, as has been stated, is the application of end-pressure; but another characteristic feature is, that the timber, during the process, is subjected to pressure on all sides, by which its fibres are prevented from bursting or from being crippled; and, in short, the timber is prevented from altering its form in any other than the desired manner. The *set* imparted to it becomes permanent after a few hours, during which time it is kept to its form by an enveloping band and a holding bolt, as shown in Fig. 432.



SEASONING OF TIMBER, AND THE MEANS EMPLOYED TO INCREASE ITS DURABILITY.

The perfect desiccation of timber appears to be one of the best means of insuring its preservation; and this has been sought to be accomplished by applying heat to the pieces of wood. This must be done gradually, as the sudden application of heat with the view of drying the timber has the effect of rending or cracking the exterior before the interior has time to dry. Burying the timber in dry sand, so that the sun may evaporate the moisture gradually, and covering it with quicklime, to produce a gradual heat, have both been resorted to—the former with success in warm countries—the latter, although making the timber dry, compact, and hard, often producing rents by the difficulty of regulating the heat. Stoves or ovens were also resorted to; but these were injudiciously constructed, and it was found that timber, when of large dimensions, could not be completely dried in them. There was no provision in them for conveying away the vapour generated by the application of the heat. But recently the plan of drying by subjecting the timber to the action of a current of air highly heated, so as to have its capacity for moisture greatly increased, has been adopted with the happiest results.

But mere desiccation does not secure the end aimed at; for it does not exhaust the vegetable matter from out

the pores of the wood: it only dries it there; and when it is exposed to humidity it becomes fluid, and resumes its tendency to fermentation.

Immersion in water for such a time as shall permit this matter to be dissolved and washed out of the wood previous to the desiccating process being applied, will secure it from the tendency to corruption when again exposed to humidity. For this, running water is obviously preferable to stagnant water; and it may fairly be inferred that to the immersion for a long time in the rivers in which they are floated down to the ports for embarkation, is to be attributed the greater durability of the pines of the Baltic, when they are properly treated by thorough drying before being used. But to render this immersion effectual, it is requisite that it be total and complete, and that it be not too long continued. It is considered that the limit of duration is from three to four months.

Immersion in hot water effects the same purpose much more rapidly; but as the wood has to be submitted to the action of the water for ten or twelve days, the expense is prohibitory of the process, unless in cases where the condensing water of a steam engine in constant operation can be made available. As we have before remarked, when speaking of the bending of timber, the action of the hot water impairs its strength, and should not be used where strength is an object.

Immersion in salt water is a means of adding to the durability of timber. It increases its weight, and adds greatly to its hardness. It is attended, however, by the grave inconvenience of increasing its capacity for moisture, which renders this kind of seasoning inapplicable for timber to be employed in the ordinary practice of the carpenter.

The water seasoning of which we have been speaking, has many objectors; and their strongest arguments are founded on the facts that there are examples of roofs which have existed for ages, the timbers of which have not been subjected to this water seasoning. But numerous experiments prove, beyond contradiction, that timber immersed in water immediately after being felled and squared, is less subject to cleave and to decay, and that it dries more quickly and more completely; which proves that the water evaporates more readily than the sap, of which it has taken the place. The immersion, however, impairs, to some extent, the strength of the timber; and this consideration indicates the applicability or non-applicability of the process. When the timber is required for purposes for which dryness and easiness of working are essential, then the water seasoning may be employed with advantage; but when for purposes in which strength alone is the great requisite, it should not be used.

Sir Samuel Bentham found, that large timber, when left with its sap-wood on, in the course of a few years had become dry, compact, and hard in the heart; but where the sap-wood had been taken off, as in sided timber, the exterior became more or less crooked and damaged before the interior was properly seasoned. The greatest objection to this mode of seasoning is its costliness, arising from the loss of interest on the capital invested.

As the condensation produced by heat increases the hardness of timber, it has been imagined that charring its surface, by increasing its hardness, would also increase its durability. In this supposition it is probable that the custom of charring the ends of piles and posts which are to be buried in the earth, has originated. The carbonized portion of the wood may, indeed, hinder the immediate contact of the humid earth with the non-carbonized wood; but it is to be questioned whether the sound timber destroyed in the charring would not have been as good an envelope as the charred surface; and taken quite as long to be destroyed by its contact with the earth as the other would act as a protection. In place of charring the ends of posts or piles, therefore, it would seem better to coat them with some substance impervious to air. But timbers buried in the earth begin as often to rot from within as from without, by the fermentation of their natural juices, as they are too often employed without being submitted to any kind of seasoning process whatever, while, in timbers so placed, the protection of thorough seasoning is especially requisite.

The gradual combination of the combustible elements of a body with the oxygen of the atmosphere, produces a slow combustion or oxidation, to which Liebig applies the term *eremacausis*.

The eremacausis of an organic matter is retarded or completely arrested by all those substances which prevent fermentation or putrefaction. Mineral acids, salts of mercury, aromatic substances, empyreumatic oil, and oil of turpentine, possess a similar action in this respect.*

Timber, after being framed, is subject to the same diseases and causes of decay as before. Often, indeed, the latent diseases only develope themselves when the timber has been worked and framed, and when the replacing of the affected by a sound piece may be very difficult, or altogether impossible.

Besides the diseases proper to the species of tree, to the soil, or to the climate, or those caused by any of the accidents which have been described, timber is liable to the attacks of insects, which are often detrimental to it, and not seldom altogether destructive of it. Among the insects whose attacks are most fatally injurious to the wood, are the white ant, the *Teredo navalis*, a kind of *Pholas*, and the *Limnoria terebrans*.

The white ant devours the heart of the timber, reducing it to powder, while the surface remains unbroken, and affords no indication of the ravages beneath.

The *teredo* and *pholas* attack wood when submerged in the sea. The *teredo*, its head armed with a casque or shell in the shape of an auger, insinuates itself into the wood through an almost imperceptible hole; it then in its boring operations follows the line of the fibre of the wood, the hole enlarging as the worm increases in size. It forms thus a tube, extending from the lowest part of the timber to the level of the surface of the water, which it lines with a calcareous secretion. A piece of timber, such as a pile in a marine structure, may be perforated from the ground to the water level by a multitude of these creatures, and yet no indications of their destructive work appear on the exterior.

The *pholas* does not attack timber so frequently as the *teredo*; and its ravages are more slowly carried on. Its presence in the wood, therefore, though very dangerous, is not so pernicious as the other.

For the protection of timber from disease, decay, and

* Liebig's *Chemistry of Agriculture and Physiology.*

the ravages of insects, various means are employed. These may be classed as internal and external applications.

I. *Preservation of Wood by impregnating it with Chemical Solutions.*

The chemicals usually employed in solution are the deutochloride of mercury (corrosive sublimate), the protoxide of iron, the chloride of zinc, the pyrolignite of iron, arsenic, muriate of lime, and creosote. They are either used as baths, in which the timber is steeped, or they are injected into the wood by mechanical means; or the air is exhausted from the cells of the wood, and the solutions being then admitted, fill completely every vacuum.

The saturation with corrosive sublimate is called Kyanizing, from the name of the inventor, Mr. Kyan. When this is performed by steeping, the time required is generally estimated as follows:—Scantlings of 14 inches square, fourteen days; of 7 inches square, ten days; and for pieces 3 inches square, seven days are sufficient.

The saturation with the solution of the chloride of zinc is the patent process of Sir William Burnett. The injecting sulphate of iron and muriate of lime is Payne's patent process. The creosote is patented by Mr. Bethell.

All of these processes are advantageous under certain circumstances; but it cannot be said that any of them is infallible. It is not easy, however, to discover whether, in cases of failure, there may not have been some defect in the process; and therefore, in important work, the additional security against the ravages of disease and decay which the impregnation gives, when properly performed, should not be neglected.

But it is to be feared that against the attacks of the marine pests—the *teredo*, the *pholas*, and the *Limnoria terebrans*—the protection these processes afford is at the best doubtful. An exception to this may probably be taken in favour of Mr. Bethell's creosote process. The soluble salts are supposed to act as preservatives of the timber, by coagulating its albumen; thus the very quality of combining with the albumen destroys the activity of the salts as poisons, and hence although preservatives against decay, they may, when thus combined, be eaten by an insect with impunity. With creosote, however, the case is different. It fills the vessels of the wood, and its smell is so nauseous that no animal or insect can bear it. It is also insoluble in water, and cannot be washed out. It is thus a protection to the wood against the ravages of insects, and also a preservative from decay. But there is great difficulty in injecting it into the heart of the wood; and into hard woods it cannot be perfectly injected. Mr. Rendell considers that for marine purposes the creosote should be used in the proportion of 10 lbs. to the cubic foot. For ordinary purposes much less is required.

Previous to the application of any of these substances, however, and as a preparative for it, it is essential that the timber be thoroughly deprived of its moisture. In regard to this, Mr. Davidson says, that—

1. Different woods and different thicknesses of wood require different degrees of heat.

2. Hard woods, and thick pieces of wood, require a moderate degree of heat, from 90° to 100°.

3. The softer woods, as pine, may be safely exposed to 120° or even to a higher temperature. When cut exceedingly thin, and well clamped, 182° or 200° have been found to harden the fibre and increase its strength.

4. Honduras mahogany boards, of 1 inch thick, may be exposed with advantage as regards colour, beauty, and strength, to even 280° or 300°. A piece of this wood $1\frac{1}{2}$ inch thick, cut fresh from the log, was deprived wholly of its moisture, amounting to 36 per cent., by exposure to a temperature of 300° for fifty hours.

But in practice, from 115° to 120° of temperature are the best calculated to secure perfect desiccation in slabs of moderate thickness. Supposing the current of heated air to be kept up during twelve hours every day with this temperature, one week may be allowed for every inch thick of the timber, up to 4 inches; but the time must be increased when the thickness exceeds 4 inches, to seven weeks for 6 inches, and ten weeks for 8 inches. If the temperature is increased, and the blast of air made continuous, the desiccation may be effected in forty-eight hours.

An exception must be made in regard to English oak, which should never be exposed to a higher temperature than 105°.

The velocity of the heated current should be 100 feet per second, and the area of outlet for the moisture and used air should be greater than the area of inlet.

When the timber is perfectly deprived of its moisture, it is in a condition for the application of the preservative agent. The different agents and processes in use may be briefly described.

Kyanizing.—In 1832, Mr. Kyan took out a patent for soaking timber in chloride of mercury or corrosive sublimate. In cases where this was properly applied, it seems to have been effective; but as it is expensive to apply the solution of sufficient strength, the process came to be imperfectly carried out, and consequently failed.

Margary's Process.—This was patented in 1837. It consisted in soaking the timber in a solution of acetate or sulphate of copper. It has been extensively used, and when the solution is of proper strength, and a sufficient quantity is absorbed, it is also efficient to a certain extent.

Sir William Burnett's Process.—In 1838, this process, which consists in impregnating the timber with a solution of chloride of zinc, was patented. The principle assumed by the patentee is, that the chloride forms an insoluble compound with the albumen of the wood; and this is the theory of action of the chemical compounds already named. It appears, however, that all such agents lose, in time, their efficacy, apparently because the aqueous portion evaporates, and the timber again absorbs the humidity of the atmosphere. The constant alternations of wet and dry so weaken the solution as to render it inoperative.

In Sir William Burnett's process, the hot solution of the chloride is forced into the timber under pressure in cylinders hermetically sealed. In heating the solution, a horse-shoe boiler on the circulating principle is used, and is found to answer well for this and for Margary's process—a sufficiently high temperature being maintained at a moderate cost.

Payne's Process.—This was patented in 1841. In this, two solutions are used in succession; the first, an earthy or metallic solution, is forced into the timber under pressure; and the second, a decomposing fluid, is then forced in, and forms with the former an insoluble compound in the pores of the wood. Thus, sulphate of iron and carbonate of soda will form oxide of iron in the cells of the timber. When this operation is well performed, as in

France, the results have been satisfactory. According to experiments made under the direction of Captain Moorsom, in 1839, it would appear that the chemical preservatives injure, to some extent, the transverse strength of the timber. The ratio of strength in Archangel deal and American pine, in their prepared and natural states, appears to be as 976 to 1000.

The value of tars and essential oils as preventives of the decay of timber has been long known, and so early as 1737, a patent was granted to Alexander Emerson for the application of hot boiled oil mixed with poisonous substances. In 1754, a patent was granted to John Lewis for the application of a varnish made from the juice of the pitch pine; and also for a process for distilling plantation tar, to be applied for the preservation of wood. None of the processes came into extensive use, chiefly on account of want of skill in their application. Mr. Bethell, in 1838, took a patent for impregnating timber with creosote; and this process is so effectual, that it is in constant use in cases where the odour of the creosote is not an obstacle to its employment.

The preservative properties of creosote are said to be owing to its coagulating the albumen, preventing the absorption of moisture, and to its being fatal to animal and vegetable life, thereby arresting the vegetation of the tree, preventing the growth of fungi, and repelling the attacks of insects.

M. Boutigny, in conjunction with M. Hutin—proceeding on the acknowledged theory, that the moisture and oxygen of the air penetrating into the heart of the wood by absorption and filtration, produce eremacausis, and that these elements of destruction appear to act chiefly at the ends of the timber—conceived that if, after the timber was completely deprived of moisture, the ends of its pores were hermetically sealed, absorption, and consequently decay, would be prevented. They accordingly introduced the system of desiccating the timber, partially charring its ends, and then immersing them in oil of schistus, or some analogous substance. This penetrates with rapidity, the ends are then blazed off, and plunged to the length of a few inches into heated pitch, tar, or gum-lac, which completely seals the pores.

Dr. Boucherie, arguing that all the changes in woods are attributable to the soluble parts they contain, which either give rise to fermentation or decay, or serve as food for the worms; and that, as the result of analysis, sound timbers contain from three to seven per cent. of soluble matters, and the decayed and worm-eaten rarely two—commonly, indeed, less than one per cent.—concludes, that since the causes of the changes it undergoes originate in the soluble matters of the wood, it is necessary, for its preservation, either to extract the soluble parts, or to make them unchangeable by introducing substances which should render them unfermentable or inalimentary. This he considers may be effected by many of the metallic salts and earthy chlorides. He shows, by experiments on vegetable matters very susceptible of decomposition, such as the pulps of carrot and beet-root, the melon, &c., which differ from wood only in the greater proportion of soluble matter they contain, that in their natural states they rapidly alter, but are preserved by the pyrolignite of iron. Dr. Boucherie conceived that if solutions of sulphate of copper, pyrolignite of iron, or other salts, could be made to take the place of the natural juices of the plant while it yet lived, the vessels of the tree would become filled with the fluid by the process which he calls *aspiration*. He supposed that by using proper solutions he should be able to protect the wood from dry or wet rot, to augment its hardness, to preserve and develope its flexibility and elasticity, to render change of form impossible, to prevent warping and cleaving, and to render it incombustible, or at least to reduce its inflammability, and, lastly, to give to it various colours and odours.

The method of proceeding first adopted was to employ the vital energy of the tree to draw the liquid into its vessels by means of the circulation of the sap. This was effected either by sawing the tree above the root, and immersing it vertically in a bath of the fluid, or by girdling the tree, that is, cutting it all round with a saw, so deep as to leave only a pin in the centre sufficient for its support, and surrounding the cut with a trough, into which the fluid was poured.

When pyrolignite of iron was the fluid used, the hardness of the timber was more than doubled. The quality of flexibility was increased by the chloride of lime and other deliquescent salts. Warping and splitting were stayed by a weak infusion of the chloride of lime. Inflammability was diminished by earthy chlorides. Mineral succeeded better than vegetable colours in the process of dyeing the wood. Resins dissolved in essential oils, by their being absorbed, rendered the wood impervious to water.

It is right to add, that Mr. Bethell, already mentioned, patented a similar process in 1838, two years before Dr. Boucherie's method was made known in France. Mr. Bethell's specification says: "Trees just cut down may be rapidly impregnated with the solutions, by merely placing the butt ends in tanks containing them. They will thus circulate with the sap throughout the whole tree; or it may be done by bags of water-proof cloth affixed to the butt ends of the trees and filled with the liquid." Pyrolignite of iron is especially mentioned as circulating freely with the sap.

But the process now adopted is that of forcing the liquid through the timber, and is carried on as follows:—After the tree is felled, a saw cut is made across its centre, and nearly through its diameter. By slightly raising the tree under the centre by a wedge, the cut is opened a little, and a piece of string is inserted in it a little within the lip or edge all round. On lowering the centre, the cut closes on the string, which forms a water-tight joint; a hole is then bored obliquely into the cut, and a hollow plug driven into it. A flexible tube is then fitted to the plug, and its other end carried to a cistern containing the solution, and placed high enough to give the requisite pressure. When the communication is completed, the liquid flows into the cells of the wood from the centre towards the ends, driving out the sap before it. When the solution appears at the ends, the impregnation is complete. When the timber cannot be divided in the middle, one of the ends is capped by a piece of board about an inch thick. This is attached by screws, or by screwed dogs. The joint is made as before, the cap is tightened up, and the liquid injected in the same manner.

To make certain that the sap has been entirely replaced by the solutions, a chemical test is applied. For example,

when the solution is sulphate of copper, a piece of prussiate of potash is rubbed on the end of the timber, when, if the solution has reached the end, a deep red-brown stain is produced.

The solution now preferred for use is formed of one part by weight of sulphate of copper, dissolved in 100 parts of water.

All woods do not, of course, absorb the same amount of solution, and the sap-wood absorbs more in proportion than the heart-wood. From this it may be inferred, which is the fact, that the process is attended with the best results when applied to the commonest and cheapest kinds of timber. The general estimate is, that the quantity absorbed is equal in cubic extent to one-half the cubic dimensions of the timber. The longer the injecting process is delayed after the felling of the timber, the slower is its progress. In newly felled timber, a log 9 feet long occupies two days, when the head pressure is 3½ feet. Three months after felling, the process would occupy three days; and four months after felling, four days. One great advantage of this process is, that the timber requires no drying or previous preparation of any kind.

II. *Preservation by Paints and other Surface Applications.*

Timber, when wrought, and either before it is framed, or when in its place, is coated with various preparations, the object of which is to prevent the access of humidity to its pores. In the application of such surface coatings, it is essential that the timber be thoroughly dry; for if it is not, the coating, in place of preserving it, will hasten its destruction, as any moisture contained in it will be prevented from being evaporated, and will engender internal decay. This result will be more speedily developed as the colour of the coating is more or less absorbent of heat.

One of the most common applications to timber constructions of large size, is a mixture of tar, pitch, and tallow. The mixture is made in a pot over a fire, and applied boiling hot. In the use of this too great caution cannot be employed to prevent danger from fire. The bridge of Dax, on the Adour, was entirely burned immediately after its construction, and when the tarring had just been completed. The pontoon on which the mixture was prepared was carefully kept to the leeward of the bridge; but the mixture in one of the pots having taken fire, and the wind changing suddenly, the flames were driven against one of the piles, which instantly ignited. The fire spread with a prodigious rapidity, enveloping in flames the whole structure, and in a short time entirely consumed it.

Another preservative for large works is painting with sand. It is thus performed:—When the wood is perfectly dry, a coating of some cheap pigment, ground in drying oil, is given to it; and while it is wet, it is dusted over with sand, either by means of a box with a perforated lid, or by a sieve, when the surface is horizontal, or simply by the hand. The sand should be purely silicious, well washed, and perfectly dry. When the first coat is quite dry, it is brushed over with a stiff brush, to detach the loose particles of sand, and then a second coat of paint is applied, and sanded over, like the first. When dry, this is brushed, and a third coat is applied and sanded in like manner. The number of coats depends on the circumstances of the case. The finishing coat should be of good oil paint of a proper colour.

When this kind of coating is executed with care and attention, it has great solidity. It fills the cracks of the timber and the joints of the framing, and is a good preservative. Its surface, however, is necessarily rough and granular; and it, therefore, is not adapted for work in which neatness is desired.

But the most universally applicable protective coating is good oil paint. To render the paint fit for works of carpentry, it is necessary that the oil should be good, the paint insoluble in water, and thoroughly ground with the oil, and that in its application it should be well brushed with the end, and not with the side of the brush. Such a coating has not the disadvantage of weight, like the painting with sand; nor does it, like it, alter the form of the object to which it is applied.

The timber to be painted in oil should be planed smooth; and it is essentially requisite that it be dry. It is usual to submit it to the action of the air for some time before painting, and then to take advantage of a dry season to apply the paint.

To render effectual any of the surface coatings we have mentioned, it is necessary to take care that the joints of framing are also coated before the work is put together. If this be neglected, it will happen that although any water which may fall on the work will evaporate from the surface, some small portions may insinuate themselves into the joints, and these remaining, will be absorbed by the pores of the wood, and become the cause of rot. The joints of all exposed work should, therefore, be well coated with the protective covering before it is put together.

Besides these fluid compositions, timber exposed to the action of marine insects is often covered with a sheathing of metal, usually copper. This metal is, however, very rapidly destroyed by the action of sea-water, and does not afford a protection against the ravages of these creatures.

Broad-headed scupper nails are sometimes used, and the corrosion which ensues by the action of the salt-water indurates the wood so as often effectually to protect it.

PROTECTION AGAINST FIRE.

To render wood incombustible has frequently been attempted, but with no great success. When we consider the number of structures which are composed of timber, and which, by a slight accident, may become a prey to fire, we cannot wonder at the many attempts which have been made to prevent such a disaster.

The means proposed have been 1st. To impregnate the wood with saline solutions; 2d. To cover it with some incombustible coating or cement; and 3d. To sheathe it with metal. All these means are attended with great expense, and incompletely fulfil the purpose. Some of the saline solutions have the effect of rendering the wood more susceptible of atmospheric influences. They enable it to resist only the first attack; as the heat augments, the water of the salts evaporates, and the salts themselves decrepitate, and leave the wood a prey to the flames. It is said, however, that Sir William Burnett's process for the prevention of decay insures also the incombustibility

of the wood; and that in the most intense fire, timber so prepared, would only be charred, and would never burst into flame.

The external coatings of non-conducting substances serve also to resist only the first attack of the flames. They are soon either detached from the timber, or they become so heated as to reduce the wood to charcoal.

Metallic envelopes, infusible at the first, become soon highly heated, and more speedily reduce the wood to charcoal than the non-conducting coverings. It is, therefore, useless to reckon on the efficacy of any of these means of rendering wood incombustible.

DESCRIPTION OF WOODS.

HARD WOODS.

THE OAK.—The oak is the greatest, the strongest, and the most durable of all the forest trees of this country. It is a native of temperate climates, and is not found in either the torrid or frigid zones. Neither is it found, even in temperate climates, at elevations where the temperature is very low. It grows naturally in the middle and south of Europe, in the north of Africa, in Asia, in Natolia, the Himalayas, Cochin-China, and Japan. In America it is abundant, especially in the United States.

Of the oak there are many species; the most common of which, as the subjects of forest culture in this country, are the *Quercus robur* or *pedunculata* (common oak), *Quercus sessiliflora* (the sessile-fruited oak). The former has its fruit on a long foot-stalk or peduncle; the latter has its fruit sessile, or on a very short stalk. The common oak is of slower growth than the other, which, moreover, tends to grow with a more erect stem and less tortuous branches. The common oak is believed to be more durable than the sessile-fruited oak; but the cause of the difference in their durability is by some assigned to the modifications produced by soil and climate.

The oak, although growing in a wide range of soils, prefers the clayey, and it is in the alluvial deposits of England and Scotland where the noblest specimens of this tree are to be found. The oak is the most solid and durable of European woods. It is certain that carpentry structures of oak timber have remained in perfect preservation for more than 600 years. When immersed in water it becomes excessively hard, and is nearly imperishable.

Although the oak does not reach the height of some of the pines and palms, and its trunk never attains the enormous magnitude of those varieties of which we have spoken, it is nevertheless found of very large dimensions. The trunks of trees of this species have been known to grow to a height of 140 feet, and to measure more than 30 feet in circumference. An enormous oak was discovered in Hatfield Bog, Yorkshire; it was 18 feet in circumference at the upper end, and 36 feet at the lower end, and although but a fragment, measured 120 feet in length.

The general height of British oaks, however, is from 60 to 80 feet; and of American oaks, from 70 to 90 feet.

The oak grows very slowly. It has been known at 100 years old to be only 1 foot in diameter. Until the age of forty years it grows pretty fast, but after that its increase becomes less and less sensible. At 200 or 300 years old, these trees are at their best. Vancouver, from observations on the growth of timber in Hampshire, arrived at the conclusion that the relative growth of wood in that county, taking the trees at ten years' growth, and the oak as a standard is—Oak 10, elm 16, ash 18, beech 20, white poplar 30. That is to say, in any given time, if the growth of oak be 1, the growth of white poplar will be 3.

In 1792, an oak at Wimbush, in Essex, measured 8 feet $5\frac{3}{4}$ inches in girth, at 5 feet from the ground; while a larch at the same height measured only 2 feet 4 inches. Thirteen years afterwards, the girth of the oak was 8 feet $10\frac{1}{4}$ inches, and of the larch 5 feet 1 inch.

Of the species in commonest use, the following are the general characteristics:—

Quercus pedunculata.—The *Quercus pedunculata*, or common oak, attains the greatest height of any of the oak species, and appears to be the most valuable, in respect of the durability of its timber. The wood is more stiff, and yet more easily split and broken, than that of the *sessiliflora.* Its colour is lighter, and its specific gravity not so great. Tredgold gives the following summary of results of his experiments on the two kinds:—

	Quercus pedunculata.	*Quercus sessiliflora.*
Specific gravity, ...	·807	·879
Weight of a cubic foot in lbs., ...	50·47	54·97
Comparative stiffness, or weight that bent the piece $\frac{7}{20}$ths of an inch, ...	167	149
Comparative strength, or weight that broke the piece, ...	322	350
Cohesive force of a square inch in lbs. ...	11,592	12,600
Weight of the modulus of elasticity in lbs. for a square inch, ...	1,648,958	1,471,256
Comparative toughness, ...	81	108

In the *Dictionnaire des Eaux et Forêts*, the following results of experiments made by Hartig, are cited:—

	Quercus pedunculata.	*Quercus sessiliflora.*
The wood, when green, weighs ...	76·13 lbs.	80 5 lbs.
When half dry, ...	65·9 „	67·12 „
When perfectly dry, ...	52·13 „	51·10 „

The discrepancy in the experiments may be caused by the different circumstances of soil and climate under which the trees were produced.

The wood of the *pedunculata* contains more of the silver grain than the other, and is, on that account, preferred, as more showy, for ornamental work. It also splits clean, which renders it suitable for split-paling, laths, barrel staves, and dowels. Its stiffness recommends it for beams, and its quality of resisting alternations of wetness and dryness renders it invaluable for piling.

Quercus Ilex.—This is a deciduous tree, and is on this account called by the French *chêne vert.* It grows in the meridional parts of Europe. It is ordinarily tortuous, which unfits it for general use in carpentry; but as its wood is hard, compact, heavy, and durable, it is employed in the construction of machines.

Quercus suber.—This species is valuable, chiefly as affording in its bark the material of which corks are made. Its wood rots rapidly when exposed to alternations of wetness and dryness.

Quercus Pyrenaica (the Pyrenean oak), called also Black Oak.—This species has more alburnum than the others. Emy says—"Its wood is very cross-grained, and

requires to be left to dry in the bark for five or six years. It is liable to the attack of worms, and grows so tough that it is difficult to work, and breaks the workman's tools. It is also knotty, and is not a good wood for carpentry."

Quercus Cerris (the Turkey, or Mossy-capped Oak).—This fine species attains a great size. Its wood is of excellent quality, and beautifully mottled. Of this kind is the oak of Holland and the Sardinian oak. The former, like all trees of humid soils and climates, grows with a straight fibre, and has soft wood, easily worked. It is not so strong or durable as the common oak; but under the name of wainscot, it is extensively used for interior finishings and for cabinet work.

The *Quercus virens* is one of the more than seventy species of oaks which are indigenous to America. Its timber in quality and in appearance approaches to that of the British oak, and in the United States it is preferred for the purposes of the ship-carpenter. The *Quercus virens* is confined to the southern states, and is not imported into this country as timber. Stevenson says, that "the sea air seems essential to its existence, as it is rarely found in forests on the mainland, and never more than fifteen or twenty miles from the shore. It is commonly 40 to 50 feet in height, and 1 to 2 feet in diameter; but it is sometimes much larger."

The *Quercus alba*, or White Oak, a native of the northern states of America, is the species from which the supply is obtained for the British market. It is not equal to the British oak in strength or durability, and it is inferior to wainscot in the beauty of its markings or *champ;* it is also of coarser grain. But its comparative cheapness causes it to be extensively used in carpentry, joinery, and cabinet-making. The best quality, where durability is required, is the second growth of New Hampshire, which is extensively used in America in ship-framing. The better the quality of this oak, the more it shrinks in drying, and it is liable to split in the sun.

The *Yellow Oak* is much used in ships for hatch-coamings, windlasses, &c.; and by agricultural implement makers for axles, as it does not split in the sun.

THE CHESTNUT (*Castanea vesca*).—The leaf is 5 to 7 inches long, and 18 to 24 lines broad, bordered with large sharp teeth. The flowers are in bunches as long as the leaves, and the fruit is within a spherical envelope, studded with spines. There are two varieties of the chestnut known in Europe. The one produces as fruit the common chestnut, which is slightly flattened by two or three growing together in the same envelope; the other produces the large chestnut, which is nearly entirely round, and each nut has a separate cover.

The chestnut sometimes grows to a prodigious size. The largest tree in Europe, the Chestnut of an Hundred Horses, on Mount Etna, is of this species. Brydone, in his *Tour in Sicily*, describes it as appearing at first sight like "a bunch of five large trees growing together;" but a short examination convinced him that it really was a single tree split into five parts. Careful measurement gave the enormous circumference of 204 feet. This tree is supposed to be more than 3000 years old. The Totworth chestnut measured, in 1830, 50 feet in circumference.

The mean diameter of this tree, however, is about 37 inches, and it grows to an average height of 44 feet. The wood is very like that of the oak, and is liable to be confounded with it. This resemblance led to the supposition that several old constructions in carpentry were formed of chestnut, but which better examinations have shown to be a variety of the sessile-fruited oak.

The chestnut was formerly much used for house carpentry and for furniture. The old wood is rather brittle and shaky, and is liable to internal decay; but the young wood is elastic and durable, and is much used for the rings of ships' masts, hoops for tubs, churns, &c. In the *Transactions of the Society of Arts* for 1789, there is an account of the comparative durability of oak and chestnut when used for posts. "Posts of chestnut and others of oak had been put down at Wellington, in Somersetshire, previous to 1745. About 1763, when they had to undergo repair, the oak posts were found to be unserviceable, but the chestnut were little worn. Accordingly, the oak ones were replaced by new, and the chestnut allowed to remain. In twenty five years (1788) the chestnut posts, which had stood twice as long as the oak, were found in much better condition than those. In 1772, a form was made partly of oak and partly of chestnut, the trees used being of the same age, and were what may be termed young trees. In nineteen years the oak posts had so decayed at the surface as to need to be strengthened by spars, while the chestnut ones required no support. A gate-post of chestnut, on which the gate had swung fifty-two years, was found sound when taken up; and a barn constructed of chestnut in 1743, was sound in every part in 1792. It should seem, therefore, that young chestnut is superior to young oak for all manner of wood-work that has to be partly under ground."

Tredgold states the weight of a cubic foot of chestnut at from 43 to 54·8 lbs., and the specific gravity of the timber at ·535. Rondelet gives ·657 as the specific gravity, and 41 lbs. as the weight of a cubic foot. The specimens shown in the Exhibition of 1851, weighed from 27·5 to 36·6 lbs. per cubic foot, and their specific gravity was respectively, ·438 and ·583. According to Tredgold, the cohesive force is from 9570 to 12,000; Rondelet says 13,300.

Its stiffness to that of oak is as	54	to	100
Its strength	"	"	48 "	100
Its toughness	"	"	85 "	100

THE ELM (*Ulmus*).—The elm is a large tree, common in Europe. Its mean height is 44 feet, and its mean diameter 32 inches. There are fifteen species. Its bark is rough and dark coloured. Its leaves are oval and toothed, and their colour is a deep rich green. Its flowers appear before its leaves, they are disposed in close bundles, and are very numerous along the branches. Its wood is ruddy brown, very fibrous, hard, flexible, and of a dense appearance, subject to warp, and tough and difficult to work.

It is subject to the attacks of worms, and in carpentry it is only used in default of better for works above ground. It is not liable to split, and bears the driving of nails or bolts better than any other wood. When constantly wet it is exceedingly durable, and is therefore much used for the keels of vessels and in wet foundations, in waterworks, for piles, pumps, and water-pipes. Its toughness fits it for the naves of wheels, shells for tackle-blocks, and for many uses in turnery, as it bears rough usage without splitting.

Wych Elm grows sometimes to the height of 70 feet, and attains a diameter of 3½ feet. The stem is less encumbered with branches; the wood is lighter, yellower, straighter and finer in the grain than the other. It is tough, and is fitted for works in which it requires to be bent; hence it is much used by coach makers for the naves, poles, and shafts of gigs and carriages, and by shipwrights for jolly boats; it is used, too, for dyers' and printers' rollers. The Scotch elm, which is much superior to the English elm, appears to be of this species. It is much finer, harder, closer in the grain, and handsomer in its appearance than the other, and is used in making articles of furniture. In days of old the wood of this species was held in esteem for the making of long bows.

Rock Elm is very like the last, and is used by boat builders.

Dutch Elm is the worst of all the species.

The *Twisted Elm* yields an ornamental wood, used for furniture.

The most profitable age for elms, both for quantity and quality of timber, is probably about fifty years.

The wood of elm is sometimes boiled to extract its sap, then washed in aqua-fortis, and stained with a tincture of dragon's blood and alkanet root, to imitate mahogany.

The weight of a cubic foot when green is about 70 lbs., when dry about 48 lbs ; and —

Its strength to that of oak is as	82	to	100
Its stiffness " "	78	"	100
Its toughness " "	86	"	100

Its absolute cohesive strength, according to Muschenbroek, is 13,200 lbs. It is said to shrink $\frac{1}{44}$th part of its width in seasoning.

The elm has been from early times much esteemed as an avenue tree; and Mr. Loudon attributes this to the following qualities—rapidity of growth, straightness of trunk, facility for topping, denseness of foliage, hardness, longevity, and the little care that it requires.

Strutt, in his *Sylva Britannica*, enumerates many elm trees of prodigious size. Among these, the Chipstead elm, 60 feet high, and 20 feet circumference at the base: the Crawley elm, on the high road from London to Brighton, the stem of which is 90 feet high, and perforated to the top; it measures 61 feet in circumference at the ground, and 35 feet round the inside at 2 feet from its base: the elms at Mongewell, in Oxfordshire, a group of giants, the principal tree being 70 feet high, 14 feet in circumference, at 3 feet from the ground: the Tutbury Wych elm, and another of the same species at Bagot's Mile, of immense size, are also figured and described in the same work.

Independently of the timber it produces, the elm tree has many economical uses. As fuel it is little inferior to the beech; the charcoal produced is, however, inferior. Its ashes are rich in alkali, the elm in this respect occupying the tenth place in a list of seventy-three trees. Its leaves and young shoots are sometimes used to feed cattle; and the leaves have been used in some places as a substitute for those of the mulberry in feeding silk-worms. They are in parts of Russia used as tea. The inner bark is used for making nets and ropes, and the bark of the American elm is soaked in water, made supple by pounding, and in the form of ribbands, used for weaving seats as rushes are.

The Walnut (*Juglans regia*).—The walnut tree is a native of Persia, and is of great size. Its branches form a noble head, and its foliage is ample, and of a fine green colour. Its trunk, in the young tree, is smooth, and of a gray colour, but as it grows old the bark becomes chapped and cleft. The walnut is grown in this country chiefly as an ornamental tree. The flexibility of its timber renders it unsuitable for beams, although it appears to have been thus used by the ancients.

There are many varieties of the walnut. Those chiefly used are two, the *Juglans alba* and the *Juglans nigra*, which are procured from America. Of these the *nigra*, or brown walnut, is the most esteemed.

The British walnut tree timber is white in the young tree, and in that state is liable to the attacks of worms. As the tree grows old, the timber darkens in colour, increases in strength and solidity, and becomes easily worked.

The timber of the walnut tree is seldom used in this country for works of carpentry, but is highly esteemed for many purposes by the cabinet-maker; and before the introduction of mahogany it took the place which that timber now occupies. On the Continent it is still prized. The makers of gun stocks consume a large quantity of it; and it is used also in making knife-handles, and in the construction of boxes and drawers to hold articles of polished steel, as it has the advantage of not acting chemically on iron or steel.

The *Juglans alba*, the white walnut, or hickory, is, as we have said, produced in North America. It is a large tree, and its timber, when young, is very tough and flexible.

The heart-wood of the black walnut, when properly seasoned, is strong, tough, and not liable to warp. It remains sound for a long time when exposed to heat and moisture. It is never attacked by worms; and it has a grain sufficiently fine and compact to admit of a high polish. The sap-wood, however, speedily decays.

In America the black walnut is very extensively used. It is split for shingles. It makes excellent naves for wheels. It is well adapted for naval purposes, as it is not liable to be attacked by sea worms in warm latitudes. On the river Wabash, canoes are made of a single trunk of this tree, sometimes 40 feet long, and 3 feet wide, and are greatly esteemed for their strength and durability. The timber is heavier, stronger, and more durable than the wood of the European walnut. It is fine grained and beautifully veined, and is susceptible of a higher polish.

The wood of the walnut, according to Loudon, weighs when green 58 lbs. 6 oz., and when dry 46 lbs. 8 oz. But according to other authorities this is much too high. Muschenbroek gives the specific gravity as ·671, the weight of a cubic foot as 41·93 lbs., and its cohesive strength at 8130 lbs.

Its strength to that of oak is as	74	to	100
Its stiffness " "	49	"	100
Its toughness " "	111	"	100

The Beech.—Only one variety of this tree (the *Fagus sylvatica*) grows in Europe. This tree grows to a great size; and its beautiful, clear, and lustrous foliage, and its shining gray bark, variegated with dark green and yellow

mosses, makes the beech much prized as a forest tree, and an especial favourite with the painter.

Its wood varies in colour from white to pale brown; its fibres are compact, but not very hard. It is easily distinguished by means of the fine and elongated *papillæ* which cover the surface on which the bark lies, and or which the impressions are seen in the bark.

When the wood is split transversely it presents brilliant satiny facets, like those of the oak, but very much smaller, and not so numerous.

The use of the beech has been long abandoned in carpentry works above ground, on account of its tendency to cleave, and its liability to be attacked by worms. The former of these defects is probably owing to injudicious felling, and, it is said, may be avoided by felling the tree at the commencement of summer, when it is full of sap, and leaving it to dry for a year after it is felled; and then, after it is squared, steeping it in soft water for six months. It will not even by this treatment be equal to oak, but will be quite suitable for second-class structures, such as piles, weirs, sluices, floodgates, and the timbering of embankments.

In this country at the present day it is used chiefly for making chairs, bedsteads, and panels for carriages, wooden screws, shovels, bakers' peels, sieve rims, and herring barrels. When used for cabinet-making, it is sometimes stained to imitate mahogany; and when for small articles, such as the handles of jugs and tea pot knobs, it is stained black in imitation of ebony. In France and Germany its uses are manifold. It is employed largely in the fabrication of furniture, and is used for the frames of saddles and horses' collars, cases for drums, felloes of wheels, bowls, porringers, salt boxes, screws, spinning wheels, pestles, presses and bellows, packing boxes, and scabbards for swords.

As fuel, beech wood is highly esteemed; it burns rapidly, with a clear bright flame, and gives much heat. The leaves of the beech are used in place of straw for stuffing mattresses; its bark is used by the tanner, and its fruit affords abundance of an excellent oil, used for burning and also for cooking.

For works which are constantly under water it is peculiarly adapted. It is also much used in the formation of tools, and in cabinet-making, and in the fabrication of a crowd of small objects. It is greatly used for sabots, into which it is converted while yet green, and then to give them durability it is exposed to a flame fed by chips of the same wood. It was formerly reduced to very thin leaves, and used for writing upon.

The weight of a cubic foot of the timber is 65 lbs. 13 oz. when green, 56 lbs. 6 oz. when half dry, and 50 lbs. 3 oz. when quite dry; or, according to Barlow, from 43·12 to 53·37; and its absolute cohesive strength 11,500 lbs.

Its strength to that of oak is as			103 to 100	
Its stiffness	"	"	77 " 100	
Its toughness	"	"	135 " 100	

The Ash (*Fraxinus excelsior*), Mr. Loudon says, "is excellent for oars, blocks, and pulleys. Few other trees become useful so soon, the wood being fit for walking-sticks at four or five years' growth, and for handles of spades, and other instruments, at nine or ten years' growth. An ash pole, 3 inches diameter, is indeed one of the most valuable pieces of timber, for its bulk, that any tree can furnish. For hop poles, hoops, crates, basket handles, rods for training plants, or for forming bowers, light hurdles, fence wallings, the branches of ash, in various stages of growth, are particularly valuable. In the neighbourhood of the Staffordshire potteries, the ash is cultivated to a great extent, and cut every five or six years for crate wood."

The ash, being hard and heavy, is little used in carpentry; but these qualities, combined with its toughness and elasticity, render it very serviceable in other arts.

Its wood is white, veined longitudinally with yellowish streaks. Its annual layers are each composed of a zone of compact wood, and another zone in which are many small pores, which show themselves as little holes when a section is made perpendicular to the fibres, and as little interrupted canals in a section parallel to the fibres.

This tree is very liable to the attacks of worms; and rots rapidly when exposed either to dampness or to alternations of dryness and moisture.

Its toughness and elasticity fit it for resisting sudden and heavy shocks. It is used in making wheel-carriages, implements of husbandry, tools, and the like, but it is too flexible and not sufficiently durable for the carpenter.

The weight of a cubic foot of the green wood is 64 lbs. 9 oz., and of the dry wood 49 lbs. 8 oz.; or, according to Barlow, from 43·12 to 53·81; and its cohesive strength 17,000 lbs.

Its strength to that of oak is as			119 to 100
Its stiffness	"	"	89 " 100
Its toughness	"	"	160 " 100

The Teak (*Tectona grandis*).—This wood is in colour light brown; it is porous, and grows quickly. In its fresh state it is more or less impregnated with an aromatic oily substance, and to this it owes much of its value. It is largely used in carpentry and in ship-building. The best kind is from Malabar.

Its specific gravity varies from ·583 to 1·056. Couch states it at ·657, and the weight of a cubic foot at 41·06 lbs.; and Barlow gives 15,000 lbs. as its tenacity per square inch. In thirty-six specimens in the Exhibition of 1851, the specific gravity was—Maximum, 1·056; average, ·711; minimum, ·583.

The Greenheart (*Nectandra rodiæi*).—This wood is a native of Guiana, where it is in great abundance. The trees square from 18 to 24 inches, and can be procured from 60 to 70 feet long. It is a fine but not even-grained wood. Its heart-wood is deep brown in colour, and the alburnum pale yellow. It is adapted for all purposes where great strength and durability is required, such as house frames, wharfs, bridges, &c. The weight of a cubic foot is from 51·15 to 61·13, and its specific gravity from ·831 to ·989.

The Poplar (*Populus*).—The wood of the poplar is soft, light, and generally white, or of a pale yellow. It has the property of being only indented and not splintered by a blow; and hence, and from its lightness, it was used for making bucklers, and this quality fits it also for the sides of carts and barrows used for conveying stones, &c. The principal use of it in construction is for flooring boards; but it requires to be seasoned for at least two

years before it is fit for use in this way. Its whiteness and closeness of grain render it easily kept clean by scouring.

It is adapted for all purposes which require lightness and moderate strength, such as for making the large folding doors of barns; and when kept dry it is tolerably durable. The old distich says—

"Though heart of oak be ne'er so stout,
Keep me dry, and I'll see him out."

In Scotland it is sometimes used for mill-work. It is made into dishes and casks by the cooper, and is also used by the cabinet-maker and turner. It is sometimes employed as a substitute for lime tree, by musical instrument makers. It weighs when green 58 lbs. 3 oz. per cubic foot, and from 24 to 38 lbs. 7 oz. when dry. It shrinks and cracks in drying, and loses about a quarter of its bulk. When seasoned it does not warp, and takes fire with difficulty. According to Bevan its tenacity is 7200, and to Muschenbroek 5500 lbs.

Alder (*Alnus*).—The wood of the alder is white when the tree is newly cut down; but the surface of the wound soon becomes of a deep red, this again fades into a pale flesh colour, which is retained by the wood in its dry state. The wood is tender and homogeneous. It has not much tenacity. It is very durable in water. Alder wood is used for all the purposes to which the soft homogeneous woods are generally applied. It is made into wooden vessels, chairs, and tables. When used for the latter purpose, the timber of the old trees, full of knots, is sought after, as it has nearly the beauty of curled maple, with the advantage of a fine deep red colour. When used in constructions above ground, it must be kept perfectly dry. Its most important applications on a large scale are for the purposes of the hydraulic engineer, such as piles for the foundations of bridges, water-pipes, and pump-barrels. Like its congeners, the willow and the poplar, the alder is serviceable to the cartwright for the sides and bottoms of stone-carts and barrows. It weighs when green 62 lbs. 6 oz., and when dry 39 lbs. 4 oz. It shrinks nearly one-twelfth part of its bulk. Muschenbroek states its tenacity at 13,900 lbs.

Birch (*Betula alba* and *Betula nigra*).—The wood of the white birch (*Betula alba*) is white, shaded with red; its grain intermediate between coarse and fine. It is easily worked when green, but chips under the tool when dry. The timber of trees grown in temperate climates is moderately durable; but that of trees grown in the extreme north is of very great durability.

The wood of the birch is used in Russia in making small rustic carriages; in France, for the felloes of wheels. Chairs and other articles of furniture are also made of it; and it is used by the cooper and the turner. The bark of the tree is used in many ways as a defence against humidity. It is laid as a coping on walls, and it is wrapped round posts and sills inserted in the ground; it is placed over the masonry of vaults, and interposed above the foundation courses of walls—a very objectionable practice. But the most familiar application of it as a protector against dampness, is the thin layer of it used as an inner sole for shoes, or a lining for hats. Its weight when green is 65 lbs. 6 oz., when dry 45 lbs. 1 oz. Its tenacity is 15,000 lbs. per square inch.

Hornbeam (*Carpinus betulus*).—The wood of this tree is white, and of a fine grain. In drying it shrinks much, which closes its pores and makes it very hard. It is of great use in framing heavy carriages and machines, and in making screws, pulleys, and the wooden teeth of wheels. Its weight, according to Rondelet, is 47·5 lbs. per cubic foot; its specific gravity, ·760; and Bevan gives 20,240 lbs. as its tenacity.

The Maple (*Acer campestris*).—The wood of the maple is moderately hard, compact, and more or less veined. It is used in various departments of architecture. It is durable when kept dry, but is liable to be attacked by worms. The wood of some of the species takes a fine polish, and is valued by the cabinet-maker. When green it weighs 61 lbs. 9 oz. per cubic foot, and when dry 51 lbs. 15 oz. Its tenacity is 10,584 lbs.

The Sycamore (*Acer pseudo-platanus*).—The wood of the sycamore when young is white, but becomes yellow as the tree grows older, and sometimes even brown towards the heart. It is compact and firm, without being hard; of a fine grain, and susceptible of a high polish. It does not warp, but is liable to be attacked by worms. It is used in joinery, turning, cabinet-making, and also by musical instrument makers. Cider-presses are made of it, and sometimes also gun-stocks. It used to be greatly in demand for making wooden dishes and spoons, when such articles were used.

Its strength to that of oak is as	81	to	100
Its stiffness " "	59	"	100
Its toughness " "	111	"	100

It weighs when green 64 lbs. per cubic foot, and when dry 48 lbs. It loses one-twelfth part of its bulk in drying. Its tenacity, according to Bevan, is 13,000 lbs. per square inch.

Lime Tree (*Tilia*).—The wood of the lime tree is pale yellow or white, close-grained, soft, light, and smooth. It cuts equally well with or across the grain, and hence is used greatly by carvers. It is used by piano-forte makers for sounding-boards. It is too soft to be employed for works of carpentry, and its use is confined to the carver, the cabinet-maker, the musical instrument maker, the turner, and the maker of toys. The weight of the cubic foot when dry, according to M. Morin, is 46 lbs.; and its tenacity, according to Bevan, is 23,500 lbs.

The Oriental Plane (*Platanus orientalis*).—Marshall classes the timber of this tree with that of the sycamore; the French writers class it with the beech and hornbeam. The natives of the East use it for carpenter work, cabinet work, and for boat-building.

M. Hassinfratz says that the wood of the plane tree weighs when dry 49 lbs. 3 oz. per cubic foot. It is of a yellowish white colour till the tree attains considerable age, when it becomes brown, mixed with jasper-like veins. In this state it takes a high polish. Bevan states its weight as 40 lbs. per cubic foot, and its tenacity 11,700 lbs.

The American, or Western Plane (*Platanus occidentalis*).—A noble tree, of very rapid growth. It bears a general resemblance to the Oriental plane, but it is larger, and more rapid in growth. It is a native of America, where it is called button-wood, and sometimes, from its habitat, the water-beech. It is also called cotton-wood, from the thick down which covers the under surface of the leaves when they first expand.

The timber, when seasoned, is of a dull red, with a fine and close grain. It shrinks much in drying, and is apt to split. Its concentric circles are divided into numerous sections by medullary rays, extending from the centre to the circumference. When the trunk is sawn in a slanting direction, these rays have a remarkable appearance. The cabinet-makers of America do not like the wood on account of its tendency to warp; but as it is easily cut in any direction, and takes a fine polish, it is well adapted for cabinet work.

The Willow (*Salix*).—The timber of the willow has a wide range of uses. It is sawn into boards for flooring, and into scantling for rafters, and in the latter capacity, when kept dry and ventilated, has been known to last for 100 years. But the purposes more peculiarly its own, are such as require lightness, pliancy, elasticity, and toughness, all of which qualities it possesses in an eminent degree. It also endures long in water, and therefore is in request for paddle-wheel floats, and for the shrouding of water-wheels. It is used in lining carts for conveying stones, or other heavy materials, as it does not splinter; and the same quality renders it fit for guard posts, or fenders.

It is also made into cutting boards; it is in demand by the turners and toymakers, and the makers of shoe-lasts. Being susceptible of a fine polish, it is dyed black, and forms an imitation ebony. Young trees, when split in two, are made into styles for ladders. The young and branch timber is made into handles for hay rakes, and other light implements, and into hop poles and props for vines. It is split and made into crates, hurdles, and hampers. The smaller rods and twigs are worked into baskets. Of the strips or shavings the bodies of hats are made. Of all the varieties of the willow, the timber of the *Salix Russeliana* is the best. This is distinguished from all other willow timber by being of a salmon colour when dry. When recently cut, the sap-wood is white, and the matured wood slightly reddish; but they both become salmon-coloured when dry.

The other varieties of willows cultivated for their timber are—*Salix alba*, which will attain the height of 60 to 80 feet in twenty years; the *Salix fragilis*, which is often confounded with the *Russeliana*—this tree grows as rapidly as the *alba*, but does not attain so great a height; the *Salix caprea* grows as fast as the *fragilis*, and will attain a height of 30 to 40 feet in twenty years. This latter tree, according to Bosc, is the most valuable of all the tree willows grown in France. The remarks on the properties of the timber apply, with slight modifications, to all these four species. The specific gravity of willow is ·390; the weight of a cubic foot 24·37 lbs. Its tenacity, according to Bevan, is 14,000 lbs.; Muschenbroek says 12,500 lbs.

Acacia (*Robinia pseudacacia*).—The timber called, commonly, *Acacia*, is the locust-wood of America. Its colour is yellow, with brown veins. M. Hartig places it, in regard to durability, next to the oak, and before the larch. In England, experiments have shown that it is heavier, harder, stronger, more rigid, and more elastic than the best oak; and it is, consequently, fitter than oak for tree-nails. When used for posts, its endurance is next to the yew. Michaux states that it lasts forty years; and on that account its great consumption in America is for sills of doors, and for the posts of the framing of half-timbered houses that are nearest the ground. It is difficult to procure the timber of large size; as even in districts where the tree thrives best, nine-tenths of the trunks do not exceed 1 foot in diameter, and 40 feet in height. Its strength to that of oak is as 135 to 100. English-grown acacia weighs 44·37 lbs. per cubic foot; its specific gravity is ·710; and, according to Bevan, its tenacity is 16,000 lbs.

The Horse Chestnut (*Æsculus Hippocastanum*).—The wood of the horse chestnut is white, soft, and unfit for purposes requiring strength and durability. It is, nevertheless, applicable to such purposes as the lining of stone carts, and it is said by Boutcher and Duhamel to be well adapted for water-pipes which are to be kept constantly under ground. It is sometimes used for flooring. When green it weighs 60 lbs. 4 oz. per cubic foot, and when dry 37 lbs. 3 oz., or, according to Loudon, 35 lbs. 7 oz.; and loses one-sixteenth part of its bulk.

The Service Tree (*Sorbus*).—The service tree, in foliage and general appearance, closely resembles the mountain ash. It attains a larger size, and bears larger fruit. In France, trees of this kind are found of the height of 50 or 60 feet. It takes two centuries to attain its full growth, and it is believed that trees exist which are upwards of 1000 years old.

The wood of the service tree has a fine and compact grain, and is of a reddish tinge. It is very hard, and takes a high polish. It is in high estimation for the framing of machinery, cogs of wheels, pulleys, screws, and for all such constructions as require great strength and the power of enduring friction. It might, in many cases, be substituted for box. It weighs when dry 72 lbs. 2 oz. per cubic foot.

The Pear Tree (*Pyrus*).—The pear tree yields a wood which is heavy, strong, compact, and of a fine grain. It is slightly tinged with red. Like the service tree, it is of great value for the parts of machines which require to endure much friction, such as screws and the teeth of cogs, and it is used largely in making handles for tools. It is easily stained black, and then so closely resembles ebony as to be with difficulty distinguished from it. It requires to be perfectly dry before it is used. The wood of the wild pear is harder than that of the cultivated pear. The weight of a cubic foot of the wood when green is 79 lbs. 5 oz., and when dry 41 to 53 lbs. Its tenacity, according to Barlow, is 9800 lbs. It shrinks about one-twelfth part of its bulk in drying.

The Apple Tree (*Malus*).—The wood of the apple tree, in its wild state, is fine-grained, hard, and of a brownish colour. It requires to be thoroughly dry before being used, and then it is easily wrought. The wood of the cultivated tree, contrary to what is usually found, has a finer grain than that of the wild tree.

The uses to which it is put are nearly the same as in the case of the pear tree; but it possesses the distinguishing qualities of the latter in a greatly inferior degree.

The wild apple tree weighs from 48 to 66 lbs. per cubic foot in a green state, and loses from one-eighth to one-twelfth part of its bulk, and about one-tenth part of its weight, in drying. The cultivated timber is heavier than the other in the proportion of about 66 to 45. Its tenacity, as given by Bevan, is 19,500 lbs.

THE HAWTHORN (*Cratægus oxyacantha*).—The wood of the hawthorn is white, hard, and difficult to work. Its grain is fine, and it takes a high polish. It is used for the smaller parts of machines, such as cogs and staves for mill-work. It is also made into hammer shafts, flails, and mallets. It weighs 68 lbs. 12 oz. green, and 37 lbs. 5 oz. dry per cubic foot; it contracts one-eighth of its volume in drying. Its tenacity is given by Bevan as 10,500 lbs.

THE BOX (*Buxus*).—This tree, which seldom exceeds the height of 12 feet in Britain, grows in Turkey as high as 25 or 30 feet, with a diameter large in proportion to its height.

The wood is remarkably heavy, and is the only European wood that sinks in water. It is yellow in colour, with a fine uniform grain. It works sweetly, and is very useful for small works exposed to great strain and friction, such as screws, and the parts for transmitting motion in machinery. It is too valuable to be used in great quantity. It is the only wood employed by the wood engravers, except for large and coarse works. It weighs 80 lbs. 7 oz. per cubic foot when newly cut, and from 60 to 68 lbs. 12 oz. when dry. Its tenacity, according to Bevan, is 19,891 lbs.; Barlow states it at 20,000 lbs. It is sold by weight.

MAHOGANY.—The mahogany tree (*Mahogani Swietenia*) is one of the most beautiful and majestic of trees. Its trunk is often 50 feet high, and 12 feet diameter; and it throws the shelter of its huge arms and beautiful green leaves over a vast extent of surface. It takes probably not less than 200 years to arrive at maturity.

The mahogany tree abounds the most and is in greatest perfection between latitudes 11° and 23° 10′ N., including within these limits the islands of the Caribbean Sea, Cuba, St. Domingo, and Porto Rico, and in these the timber is superior in quality to that of the adjacent continent of America, owing, it is to be supposed, in some measure, to its growing at greater elevations and on poorer soils.

Mahogany timber was used at an early period by the Spaniards in ship-building. In 1597 it was used in the repairs of Sir Walter Raleigh's ships in the West Indies. It was first imported into England in an unmanufactured state in 1724.

The finest mahogany is obtained from St. Domingo, the next in quality from Cuba, and the next from Honduras.

In the island of Cuba the tree is felled at the wane of the moon from October to June. The trunks are dragged by oxen to the river, and then, tied together in threes, they are floated down to the rapids. At the rapids they are separated and passed singly, then, collected in rafts, they are floated down to the wharves for shipment. It is considered essential to the preservation of the colour and texture of the wood, that it should be felled when the moon is in the wane.

The Honduras mahogany is commonly called Bay wood, and is that most used for the purposes of carpentry. It recommends itself for these purposes by its possessing, in an eminent degree, most of the good and few of the bad qualities of other timber. It works freely; it does not shrink; it is free from acids which act on metals; it is nearly if not altogether exempt from dry rot; and it resists changes of temperature without alteration. It holds glue well; and it does not require paint to disguise its appearance. It is less combustible than most woods. The weight of a cubic foot is 50 lbs., and its tenacity is given by Barlow at 8000 lbs.

Representing the strength	of oak by 100, that	of Bay	wood is	96
"	stiffness of oak by 100,	"	"	93
"	toughness of oak by 100,	"	"	99

SABICU.—The wood of a beautiful tree which grows in Cuba. It is used in the government yards for beams and planking. The weight of a cubic foot is from 57·5 lbs. to 65 lbs. It has been recently used by Sir William Cubitt for the deck floor of the great landing stage at Liverpool.

RESINOUS WOODS.

Of the timber of the resin-producing trees, belonging to the natural order Coniferæ, many varieties are used by the carpenter. The yellow deal of Europe, the produce of the *Pinus sylvestris;* the white deal of Norway, the timber of the *Abies excelsa;* the white pine of America, which is the *Pinus Strobus;* the yellow pine of America, *Pinus variabilis;* the pitch pine, *Pinus resinosa;* the silver fir, *Pinus Picea;* and the various white firs, or deals, the produce of the *Pinus Abies*, or spruce fir; and also the larch; are all used in almost every kind of construction for shelter or for ornament.

No other kind of tree produces timber at once so long and straight, so light, and yet so strong and stiff; and no other timber is so much in demand for all the purposes of civil architecture and engineering.

Log-houses are more conveniently made of the timber of the pine than of any other, because it can be obtained of great length with little taper. In Russia and America roads are made of the trunks of pines. They are rough, it is true, and are very significantly called corduroy roads; but still by their use access is obtained to places which, but for the facilities these trees afford, would be inaccessible.

From the growing trees are obtained turpentine, liquid balsam, and the common yellow and black rosin of the shops. Tar is obtained by cutting the wood and roots into small pieces, and charring them, or distilling them in a close oven, or in a heap covered with turf. The lampblack of commerce is the soot collected during this process. Fortunately, the trees of the pine and fir tribe, so useful to man, are found in great abundance in America and Europe.

The European pine and fir timber is obtained from the extensive forests of Sweden, Norway, Prussia, Russia, Poland, Germany, Austria, and Switzerland. In many of these places in the Alpine districts, the forests are inaccessible; and in others, the timber cannot be made available from the difficulty of conveying it to the streams or rivers which would bear it down to the ports for shipment. In Sweden the principal river by which the timber of that country is floated to the sea is the Gota. It is conveyed by it to Gottenburg. It is also shipped from Stockholm and Gefle. The timber of Norway is floated down the Glommen to Christiana, whence it is called Christiana deal; and down the Drammen to Dram or Drontheim, whence it is called Dram timber.

From the immense forests of Prussia, Russia, and Poland, the timber is brought down the rivers into the ports on the southern shores of the Baltic, whence it is

called Baltic timber. The chief ports are Memel, Danzig, Riga, Petersburg, Archangel, and Onega. The river Memel being the principal channel through which the pines grown in the north of Prussia reach the sea at the town of that name, the timber they produce is known as Memel timber. The forests of West Prussia and Poland yield timber of a better quality, which, floated down the Vistula and the Bug to Danzig, is known as Danzig timber. The best of the Baltic timber is that which, grown on the banks of the Dnieper, is transported to the Dwina, and then, being rafted down to Riga, comes into the market as Riga timber.

In the transport of the pines from the Alpine forests, advantage is taken of the slope, and shoots are made, in which the large trees hurry with astonishing velocity to the plains below. When the nature of the ground will not admit of the shoot being formed on the surface with a uniform slope, constructions of great magnitude, made of timber, are carried over gorges and ravines, and even across valleys. These shoots are troughs, the bottoms and sides of which are formed of the trunks of trees. They have such a slope as causes the trees to descend by the force of gravitation alone. The slope required, it is found, need not exceed 20°; and to diminish the friction, a stream of water is made to flow along the shoot. Sometimes, to preserve the timber from injury, it is attached to a species of rude sledge. Of these shoots, the most remarkable for extent, and for boldness of design and construction, was the inclined plane of Alnpach. The pines of the forests on Mount Pilat—pines of the largest and finest quality—rotted where they grew, from the difficulty of transporting them to the rivers. The proprietors of these forests were fully aware of the value of their timber if it could be transported to the rivers; but the boldest and most skilful shrunk from encountering the difficulties that lay in the way of such an enterprise as constructing a shoot in such wild regions. In 1816, however, M. Rapp found three proprietors bold enough, along with himself, to make the attempt. They commenced to make an inclined plane of three leagues in length, and with an uninterrupted slope, to the Lake of Lucerne. The channel of the shoot was 6 feet wide, and 3 feet deep; its bottom was formed of three trunks of trees, placed in juxta-position. In the centre one of the three was formed a channel, into which was turned a stream of water, alimented at frequent intervals along the line.

The inclined plane in its course had 2000 points of support. In several places it was attached to the wall-like sides of the rocks along which it had to be carried. It bridged over ravines sometimes at an elevation of 120 feet; and at one point, in order to maintain the slope, it had to be carried through the earth in a tunnel.

Wherever practicable, its direction was in right lines, but these could not always be maintained; and where a bend had to be introduced, it was formed on a wide curve.

Great as this work was, it was completed in eighteen months by 160 workmen. It was constructed without a single piece of iron being used in fastening it. It consumed 25,000 trees, and cost £4167 sterling. Other authorities state the cost at £9000, and the date of construction 1812.

From point to point along the line a chain of workmen was established to watch the progress of the trees, and ascertain the time that tree might succeed tree in their passage without danger. By this living telegraph communication was established between the extremities in three minutes.

Pines of 100 feet long, and 10 inches diameter at their smallest end, flashed with such velocity past the watchers, that they appeared only a foot or two in length. They passed from the summit to the lowest extremity in two minutes and a half.

To learn the effects produced by such a velocity, obstacles were placed in the groove so as to throw the trees out in their passage. They were thrown from the channel with such force as to enter the ground to the depth of 18 to 24 feet, and one of them striking a tree growing near, split it as if it had been burst by gunpowder.

The credit of this magnificent work is entirely due to M. Rapp, who fought his way against a host of prejudices, and overcame difficulties innumerable.

The following is a summary of the purposes for which the woods of the various European firs and pines are best adapted. "Memel is the most convenient for size; Riga, the best in quality; Danzig, when free from large knots, the strongest; Swedish, the toughest. For framing, the best deals to be depended on are the Norway, particularly the Christiana battens; and for panelling, the white Christiana; yellow Christiana deals have much sap, and, consequently, cause waste. The best for upper floors are Dram and Christiana white battens; and for ground floors, Stockholm and Gefle yellows. For staircases, Archangel and Onega planks. Swedish deals are not to be depended on for framing, on account of their warping."*

Pinus sylvestris.—Red or yellow pine is the produce of the *Pinus sylvestris*, the wild pine, or Scotch fir. The timber grown in Britain, especially in the southern parts of it, is not so valuable as that produced in the Alpine countries. There are, indeed, exceptions, but this appears to be the rule. It is not so sound; it is coarser in the fibre, it contains more sap-wood, and is not so strong nor so durable. Dr. Smith, however, in his essay on the production of timber, says, that he has seen some Scotch fir grown in the North Highlands, which formed the roof of an old castle, and after 300 years it was as fresh and full of resin as newly-imported Memel.

But although the home-grown timber is, in point of fact, less strong and not so durable as that which is imported, it is worth while to inquire whether much of this difference of quality is not occasioned by the treatment the tree receives. Making every allowance for the inferior timber produced by planting the Scotch fir on a soil and in a climate not suited to the habits of the tree, it is still hard to believe that, when the soil and climate are judiciously chosen, the timber produced must be so very greatly inferior in quality to the foreign timber. In the Alpine forests the tree is felled at its maturity; it is squared, weather-seasoned, and then water-seasoned in the course of its progress to the port where it is shipped. It is received in this country after a long interval, and in the hands of the user it is again submitted to a more perfect seasoning and drying before it is

* Laxton's *Builders' Price-Book.*

finally wrought up. Here, on the contrary, the tree is felled before it attains maturity, the whole process of felling, barking, seasoning, and working, are very quickly gone through, and the timber is generally in its place in the building, whose construction is the immediate cause of the tree's destruction, in the widest sense, within six months after the time the tree was marked for the axe. Is it a thing to be wondered at, then, that the foreign timber should possess such a superiority over that grown in this country?

Home-grown timber may never rival that from abroad in strength and durability; but a proper attention paid to the selection of the trees, and to the subsequent processes of felling, storing, and seasoning, would render it available for many purposes to which it cannot now be applied; would give durability to such of it as is used in the timbering of farm buildings, its present most frequent application, in place of the decay which renders reconstruction a necessity at every renewal of a lease. As a proof that these remarks are not uncalled for, it is only necessary to refer to the excellence of the timber grown in Mar Forest, where due attention has been paid to its selection, cutting, and seasoning.

The best wild pine timber is that from the northern parts of Europe, whence it comes in the shape of logs, deals, and spars.

The wild pine timber is the most durable of the pine species. Brindley, the celebrated canal engineer, was of opinion that it is as durable as oak. Mr. Semple, the engineer, in his treatise on building in water, expresses a similar opinion. Duhamel states, that on the piles of an old church, which had existed many centuries, being taken up, they were found to be perfectly sound at the centre, with a resinous smell, although the outside was a little decayed.

The lightness and stiffness of the Scotch pine timber renders it superior to every other kind of timber for beams, girders, joists, rafters, and, indeed, for framing in general. For joiners' work, too, it is well adapted, as it is easily worked, and stands better than the harder woods, and if not so durable, which is questionable, it is certainly very much cheaper than they.

In the best timber, the saw should leave a clean surface, not covered with woolly fibres; the annual layers should be thin, never exceeding one-tenth of an inch in thickness. The Riga and Norway timber, as we have said, is the best, and Memel is very little inferior, and being stiffer, it is better adapted for some purposes.

In the inferior sorts, the annual layers are thick and soft, the dark part of the ring of a honey yellow. The wood feels clammy; it is heavy, and chokes the saw in cutting. Such timber should not be used where durability is required, or where it will be exposed to great strains. In other kinds, the wood, although not heavy, is spongy, and in cutting it the saw leaves a woolly surface. The Swedish timber has often these peculiarities, and is, in such cases, deficient in strength and stiffness.

Of the timber of the *Pinus sylvestris*, Memel supplies three qualities, viz.:—

Crown, in baulk, 13 × 13 inches, and from 28 to 50 feet long. Longer timber is apt to be knotty at the small end.

Best Middling.

Second Middling, or *Brack.*

These are of about the same dimensions as crown, but as they contain large knots, they are not so fit to be cut into small scantlings.

Danzig common baulks are from 14 to 16 inches square. Crown baulks are sometimes so large as 26 and 30 inches, and so long as 70 feet; but 40 feet is nearer their average length. As this timber is very sound, it should be used where whole timbers are required; the crown is especially useful for bearing timbers.

Riga baulks are 13 to 14 inches square, and average about 40 feet long. The heart of the baulk is often shaky; it should, therefore, be divided longitudinally, and the flitches reversed. It is very hard to tell the difference between Memel and Riga timber when in the log.

Norway timber is of smaller dimension than that from Prussia and Russia. It is very durable, and suitable for exposed work, and should be used where the beams do not require to exceed 11 inches square. The timber is also supplied in planks, deals, and battens; and their characteristics may be briefly stated as follows, viz.:—

Prussian, Memel, and Danzig.—Very durable, adapted for bridge flooring and external work.

Russian, Archangel, and Onega.—Not fit for work exposed to damp. The knots are often surrounded by dead bark, and drop out when the timber is worked. Clean specimens are suitable for joiners' work.

Petersburg and Narva.—Easily takes dry rot in damp unventilated situations.

Biornburg.—The planks are 12 feet long, and are like those of Archangel, but more knotty.

Finland and Nyland.—These are 14 feet long. They are fit for the carpenter only, and are very durable.

Norwegian, Christiana, and Dram.—Deals and battens. The Christiana deals have generally much sap-wood, and, consequently, cause loss and waste in working. The wood is mellow, and works well under the plane. Of the Dram timber, the upland is the best, the lowland the worst.

Frederickstadt.—Durable and mellow, works easily under the plane.

Swedish, Stockholm, Gefle.—Full-sized, and free from sap; but liable to warp, and to be full of large coarse knots. It is useful for ordinary carcass work where cost is an object, as it is cheaper than Norway timber.

Gottenburg.—Durable, and fit for the carpenter, but not for the joiner.

Hernösand and *Sundsvall.*—Same characteristics as the last, with all the faults to a greater extent.

Tredgold gives the following as the relative strength of foreign pine and of that grown in England, and also in Mar forest, and of oak:—

	Foreign Pine.	English Pine.	Mar Forest Pine.	Oak.
Strength,.........	80	60	61	100
Stiffness,..........	114	55	49	100
Toughness,.......	56	65	76	100

The best foreign timber shrinks about $\frac{1}{80}$th part of its width in seasoning from the log.

White Fir, or Deal (European).—This is the produce of the *Pinus Abies*, or Norway spruce. It is light, elastic, but varies in durability with the conditions of soil and climate. It is much less resinous than the Scotch fir,

and its colour is a reddish or yellowish white. This tree affords the Burgundy pitch of commerce, and its bark is used for tanning.

The timber being fine-grained, takes a fine polish, and is easily worked, either with or across the grain. It holds glue remarkably well.

The spars are from 30 to 60 feet long, and from 6 to 8 inches thick, and are used for scaffold poles, ladders, oars, and masts to small vessels.

The American spruce is of two kinds—the White Spruce (*Pinus alba*), and the Black Spruce (*Pinus nigra*). The white American spruce timber is not so resinous as the Norway spruce, nor so heavy; but it is tougher, and is more liable to twist and warp in drying. It decays soon. It is imported in deals and planks.

The black spruce is said to produce the best wood; but as it is the bark and not the timber which gives it the distinctive appellation, it is not possible to tell the difference, when the wood comes mixed in its cut state. Its distinguishing characteristics, according to Michaux, are strength, lightness, and elasticity. In Maine and Boston it is much used for the rafters of houses.

The peculiar characteristics of the European spruce timber may be briefly stated as follows:—

Norway Timber.—White deals from Christiana, Frederickstadt, and Dram. The two first are of the best description; but in those from Frederickstadt the knots are often surrounded by adhering bark, and are apt to drop out when they are sawn into boards.

The lowland Dram timber is apt to shake and warp in drying; the upland deals have not this tendency, and are, therefore, to be preferred.

Swedish Timber.—Gottenburg white deals are hard and stringy, and fit only for temporary work. The same remark, in a greater degree, applies to those from Hernösand and Sundsvall.

Russian Timber.—Narva white deals are nearly equal to the Norwegian, and so also are those from Riga, when properly seasoned.

Petersburg white deals, however carefully seasoned, expand and contract with every change of weather.

American white spruce deals warp and twist very much, and soon decay. They are fit for temporary purposes only.

White deal shrinks $\frac{1}{70}$th in becoming perfectly dry, and what are termed dry deals will shrink $\frac{1}{80}$th.

Regarding oak as 100, the strength, &c., of spruce, are—

	American Spruce.	Norway Spruce.	British Spruce.
Strength,.....................	86	104	70
Stiffness,.....................	72	104	81
Toughness,..................	102	104	60

Pinus Strobus, the Weymouth pine, or yellow pine, the timber of which, called American white pine, is imported in large logs. Its wood is light and soft, straight-grained, and free from knots, which fits it for joiners' work, especially for mouldings. Its colour is a brownish yellow, and the colour and texture are very uniform. It has a peculiar odour.

Michaux, in his *North American Sylva* (1819), says, "Seven-tenths of the houses, except in the larger capitals, are built of wood, and about three-quarters of these are built almost entirely of white pine; and even in the cities, the beams and principal wood work of the houses are of that wood. The ornamental work of the outer doors, the cornices and friezes of apartments, and the mouldings of fire-places, all of which, in America, are elegantly wrought, are of this wood. It receives gilding well, and is, therefore, selected for looking-glass and picture frames. Sculptors employ it exclusively for the images that adorn the bows of vessels, for which they prefer the kind called the pumpkin pine. At Boston, and in other towns of the northern states, the inside of mahogany furniture and of trunks, the bottoms of Windsor chairs of inferior quality, water-pails, a great part of the boxes used for packing goods, the shelves of shops, and an endless variety of other objects, are made of white pine. In the district of Maine it is employed for barrels to contain salted fish, especially the variety of the timber called the sapling pine, which is of stronger consistence." But the most important information given by Michaux to the carpenter, is, that in the construction of the magnificent wooden bridges over the Schuylkill at Philadelphia, and the Delaware at Trenton, and also in the bridges which unite Cambridge and Charlestown with Boston, of which the first is 1500 feet, and the second 3000 feet in length, the white pine has been chosen for its durability.

The white pine is also used for shingles and clapboards. The shingles are commonly 18 inches long, from 3 to 6 inches wide, $\frac{1}{4}$-inch thick at one end, and 1 line at the other. They are made only of the perfect wood, and should be free from knots. In America they last from twelve to fifteen years. They are exported in great quantities to the West Indies.

But however high this pine may rank in America as a timber for the carpenter, it is not esteemed in this country. It is inferior to the Baltic timber in strength and hardness, and is not to be compared to it in durability. It is liable to dry rot, and is, therefore, and for the other reasons given, never employed in the carpentry of the best buildings, but is exclusively used by the joiner.

Its strength to that of oak is as	99	to	100
Its stiffness " "	95	"	100
Its toughness " "	103	"	100

PITCH PINE (*Pinus resinosa*).—This pine is highly esteemed in Canada for its strength and durability. Its timber is close-grained, and the concentric circles small. It is exceedingly resinous, and consequently heavy. Its elasticity is remarkable, it may be bent round the bow of a vessel, and after some years it will recover its straightness. The long-leaved Florida pine yields the best quality; and the fine-grained timber is alone used by the American government. The pitch pine grown in the northern states in Virginia is not so good, as there the trees are tapped for the pitch, which injures the durability of the wood. It is employed in furnishing planks and deck planks for ships, both in this country and in America. Sometimes planks are obtained 60 feet long without a knot. Stripped of its sap-wood, it makes excellent pumps and troughs for mills, and may be used in situations where it is exposed to damp and dryness, but will not last under ground so long as white pine. It is of a redder colour than Scotch pine, and is sticky and difficult to plane. Its strength compared with oak at 100 is 82; toughness, 92.

THE SILVER FIR (*Pinus Picea*).—This fir, from which the Strasburg turpentine is obtained, produces a timber which is elastic, light, and stiff. Its grain is irregular,

as the fibres which compose it are partly white and tender, and partly yellow, or fawn-coloured, and hard. The narrower the white lines are, the more beautiful and solid is the wood. It is used in carpentry works of all kinds. In England it has been used chiefly for floors; and its stiffness gives it an advantage in the case of any slight sinking. Like all of the pine tribe it shrinks considerably in drying; yet Arthur Young and Mitchell affirm that floors of the timber of a full-grown tree may be laid immediately on its being sawn up without risk of shrinkage.

LARCH (*Larix europæa.*)—The larch is a deciduous tree, frequently attaining great size. It is a native of the mountainous regions of Europe, the west of Asia, and North America. It is found in abundance in the Alpine districts of the south of Germany, Switzerland, Sardinia, and Italy, but not on the Pyrenees, nor in Spain. Of late years it has been extensively cultivated in Great Britain.

Among the Romans the larch was highly esteemed for its strength and durability. Its timber was used in the construction of the forum of Augustus, and several bridges in Rome. Vitruvius mentions it, and attributes the decay of buildings in his time to the fact of larch not being used in their construction. The first account of larch trees growing in Britain is in 1629. They are at that time spoken of by Parkinson in his *Paridisus*, as being "rare, and nursed with but a few who are lovers of variety." Evelyn mentions a large one of "goodly stature," as growing in 1664, at Chelmsford, in Essex. Miller, in 1731, says, "This tree is now pretty common in English gardens." In the account of the Duke of Athole's larch plantations, published in the *Highland Society's Transactions*, it is stated that Goodwood, the seat of the Duke of Richmond, near Chichester, was probably the first place where the larch was cultivated as a forest tree, and that only on a limited scale. In 1782, an extensive plantation was formed at Halford; and shortly afterwards the Society of Arts offered premiums for planting the larch, and making known the useful properties of the timber. Public attention was thus drawn to the value of the larch, and the result was that it was extensively planted throughout Britain.

In Scotland it is said that the first larch planted is the one known as the crooked larch at Dalwick, in 1725. The popular account, however, is that the Duke of Argyle introduced the larch into Scotland in 1727. Having received them among some exotics from Italy, he treated them all in the same manner, and placed them in a hot-house; when very soon the larches withered, and being supposed dead, were thrown out on a heap of rubbish in a garden. Here they revived, and sending forth shoots, became vigorous trees. In the account in the *Highland Society's Transactions* before alluded to, it is said that "in 1738 Mr. Menzies, of Migeny, in Glen Lyon, brought a few plants of the larch in his portmanteau from London, five of which he left at Dunkeld, and eleven at Blair in Athole for Duke James." But whether this be the correct account of its introduction or no, it is indisputable that it was first extensively planted in Blair and at Dunkeld by the Duke of Athole. Between 1740 and 1750 he planted 350 larches at Dunkeld, at an elevation of 180 feet above the sea, and 873 at Blair. In 1759 he planted 700 larches, with the view of experimenting on its value as a timber tree. This plantation was on the face of a hill, from 300 to 400 feet above the sea, and on very poor land. His successor, John, Duke of Athole, between 1764 and 1774 planted 410 acres Scotch, and his plans embraced the planting of 225 acres more. His successor completed this, and during his life continued planting, until, in 1799, he had planted, at Logierait, Inver, and Dunkeld, altogether, 800 acres Scotch. In 1800 he continued his operations, and from that date to 1815, completed the planting of 2409 Scotch acres. Some of the land thus planted was at an elevation far exceeding the range of growth of the Scotch fir, being from 900 to 1200 feet above the sea. The success which attended the experiment induced him to continue planting till 1826, and at the close of that year he had completed the planting of 8071 Scotch acres with larch alone, or with larch mixed with other trees 8604 Scotch, or 10,324 statute acres.

In France attention was early directed to the value of larch timber; and in 1798 a commission was appointed to examine into its suitableness for the construction of ships. The result, as reported, was:—1. That the wood was more resinous than that of *Pinus Laricio*, though, at the same time, lighter in the proportion of 25 or 26 to 29. 2. That its fibres were very strong and able to resist twisting. 3. That branches, clear from knots, might be used as topmasts.

The wood of the larch, according to Hartig, weighs 60 lbs. 13 oz. per foot when green, 36 lbs. 6 oz. when dry. The wood of trees produced in a good soil is of a yellowish white; but that of trees grown in a poor soil, and at great elevations, is reddish brown, and very hard. The timber is said to arrive at perfection in forty years; while the Scotch pine takes eighty years to mature its timber.

From the nature of its growth, the larch is free from large knots; and although it produces dead knots, yet these are generally sound, and found fast-wedged, as it were, in the timber. It is exceedingly durable, excelling, in this respect, even the oak itself. In timber constructions it is applicable, in large baulks, or scantlings, as beams and lintels; but when cut into deals, or smaller scantlings, its tendency to warp or twist is so great, as to render it much less valuable in this condition. It is said, however, that if the tree is barked two years before it is cut, the timber loses this tendency. It is difficult to work.

As post-piles, or sleepers, or in circumstances in which it is alternately exposed to wet and dry, its durability is very great. Hence, also, it is suitable for mill-work, for the steps of quays, &c.

Its strength to that of oak is as	103	to	100
Its stiffness " "	79	"	100
Its toughness " "	134	"	100

THE CEDAR.—Under the general name of cedar are known to us, the red cedar (*Juniperus Virginiana*), a native of North America; the white cedar (*Cupressus thyoïdes*), also an American tree; the cedar of Lebanon (*Cedrus Lebani*). Of these, the first-named is probably the most familiarly known, by its wood being used for blacklead pencils. The name red cedar has reference to the wood of the heart of the tree merely, for the sapwood is perfectly white. It is so strong and durable that it would be preferred to every other kind of wood for rural purposes in America, were it not so scarce and high-priced. It is admirably adapted for subterranean water pipes. It is used for the upper parts of the frames of vessels. In this country it is much used for drawers,

wardrobes, and other articles of furniture, as it is not liable to be attacked by insects; and on account of its power of resisting heat, Mr. Brunel has used it for covering locomotive boilers.

The timber of the white cedar, from its lightness and its power of resisting alternations of dryness and moisture, is in common use in Baltimore and Philadelphia for shingles. These are cut transversely to the concentric circles; they are from 2 to 2 feet 3 inches long, 4 to 6 inches broad, and 3 lines thick at the larger end. At Baltimore they are called juniper shingles. These shingles are much more durable than those of the white pine; lasting from thirty to thirty-five years. It is made into pails, buckets, wash tubs, churns, &c.; and the coopers in Philadelphia who make these articles are called cedar coopers.

The cedar of Lebanon has timber of a reddish white colour, light, spongy, and easily worked, but very apt to shrink and warp, and by no means durable. In its appearance it bears a close resemblance to the timber of the silver fir. The weight of a cubic foot of red cedar is 26·0 lbs.; its specific gravity is ·426. Couch gives ·753 as the specific gravity of Canadian cedar, and 47 lbs. as the weight of a cubic foot; and Bevan states its tenacity at 11,400 lbs. per square inch.

THE YEW (*Taxus*).—The yew is a very slow-growing tree; but if it live a long time it becomes colossal in its dimensions. At Foullebec in France, there is a yew tree 21 feet in circumference. In England there are many noble trees of this kind; and at Fortingall, in Scotland, there is one, or rather the wreck of one, which was found by Mr. Tennant to be 56 feet in circumference. As the tree grows very slowly (so many as 150 annual layers have been counted in a tree of 13 inches diameter), the Fortingall yew must have been a flourishing tree at the commencement of the Christian era.

The wood of the yew is hard, compact, and of a very fine grain. It is flexible, elastic, and incorruptible. It splits easily. The sap-wood, which is white, and does not extend to a great depth, is also very hard. The heart-wood is of a fine orange or deep brown colour. It requires a long time to dry, but shrinks very little in drying. It is the finest wood for cabinet-making purposes, and is generally employed in the form of veneers. Where it is found in sufficient quantity to be used for large works, the yew may be considered to be indestructible, even where the most durable of other woods perish. In France the timber makes the strongest of all wooden axle-trees. The weight of the specimen in the Exhibition of 1851 was 41·7 lbs. per cubic foot, and its specific gravity ·665. Muschenbroek gives 50·43 lbs. as the weight of a cubic foot, and ·807 as the specific gravity of Spanish yew; and Bevan gives 8000 lbs. as its tenacity.*

THEORETICAL CARPENTRY.

RESOLUTION AND COMPOSITION OF FORCES.

CARPENTRY is the art of combining pieces of timber to support a weight, to sustain pressure, or to resist force.

It is broadly distinguished from *joinery* by this, that while the work of the carpenter is essential to the stability of a structure, the work of the joiner is applied more to its completion, its decoration, and rendering it fit for use, and may, in general, be removed without affecting its stability.

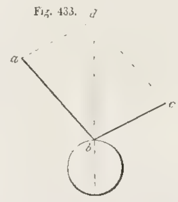
The principles of carpentry are founded on the doctrine of the composition and resolution of forces—a knowledge of the relative strength of the materials; and it is through a knowledge of these alone that skilful designs are made.

The effects of the different forces which act on a piece of timber at rest are these—extension and compression in the direction of its length, lateral compression, and torsion. To the first, is opposed cohesion; to the second, stiffness; to the third, transverse strength; and to the fourth, the elasticity of torsion. On these resistances of materials, direct experiments have been made, and practical formulæ for calculating them have been deduced.

It is essential, on entering on the subject, that an accurate idea should be formed of the manner in which several forces act when united in their effect, and we shall therefore proceed to lay before our readers the principles of the composition and resolution of forces when accommodated to the chief purposes of the carpenter.

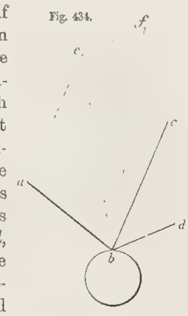
If a (Fig. 433) be a force acting on a body in the direction of the line $a\,b$, and c another force acting on the same point in the direction of the line $c\,b$, with pressures in the proportion of the length of the lines $a\,b$ and $c\,b$ respectively, then the body will be affected precisely in the same manner as if acted on by a single force d, acting in the direction $d\,b$, with a pressure proportioned to the line $d\,b$, which is the diagonal of a parallelogram formed on $a\,b$, $c\,b$, and which is called the *resultant* of the two forces $a\,c$.

Fig. 433.



In like manner, if the forces a, c, d (Fig. 434), act on a body b, in the direction of the lines $a\,b$, $d\,b$, $c\,b$, and with intensities proportioned to the length of these lines, then the resultant of the two forces, a and c, is expressed by the diagonal $e\,b$ of the parallelogram, formed on the lines $a\,b$, c, b, and the resultant of this new force e, and the third force d, is f acting in the direction $f\,b$, the diagonal formed on $e\,b$, $d\,b$; therefore, $f\,b$ expresses, in direction and intensity, the resultant of the three forces a, d, c. In like

Fig. 434.



* *Loudon; Strutt; Tredgold; Barlow; Bevan; Rondelet; Emy; Michaux; The Mahogany Tree; Report of the Juries, Exhibition,* 1851; Low *on Landed Property; Morton's Cyclopedia; Ponts et Chaussees; L'Ingeneur Civile,* &c.

manner, the resultant of the forces $a\ b\ c\ d\ e$ (Fig. 435) will be found to be h, acting in the direction $h\ o$. A simple experiment may be made to prove this. Let the threads $a\ b$, $a\ c\ d$, $a\ e\ f$ (Fig. 436) have the weights $b\ d\ f$ appended to them, and let the two threads $a\ c\ d$, $a\ e\ f$ be passed over the pulleys c and e; then if the weight b be greater than the sum of $d\ f$, the assemblage will settle itself in a determinate form, dependent on the weights. If the three weights are equal, the lines $a\ c$, $a\ e$ of the threads will make equal angles with $a\ b$; if the weights $d\ f$ and b be respectively 6, 8, and 10, then the angle $c\ a\ e$ will be a right angle, and the lines $c\ a$, $e\ a$ will be of the respective lengths of 6 and 8; and if we produce $c\ a$, $e\ a$ to n and m, and complete the parallelogram $a\ n\ o\ m$; $a\ n$, $a\ m$ will also be 6 and 8, and the diagonal $a\ o$ will be 10. The action of the weight b in the direction $a\ o$ is thus in direct opposition to the combined action of the two weights $d\ f$, in the directions $c\ a$, $e\ a$; and if we produce $o\ a$ to some point k, making $a\ r$, $a\ s$ equal to those weights, we shall manifestly have $a\ k$ equal to $a\ o$. Now, since it is evident that the weight b, represented by $a\ o$, would just balance another weight l, pulling directly upwards by means of the pulley k, and as it just balances the two weights $d\ f$, acting in the directions $a\ c$, $a\ e$, we infer that the point a is acted on in the same manner by these weights as by the single weight, and that two pressures acting in the directions and with the intensities $a\ c$, $a\ e$ are equal to the single pressure acting in the direction and with the intensity $a\ k$. In like manner, the pressures a, $s\ a$ are equivalent to $n\ a$, which is equal and opposite to $r\ a$; also, $o\ a$, $r\ a$ are equivalent to $m\ a$, which is equal and opposite to $s\ a$.

Fig. 435.

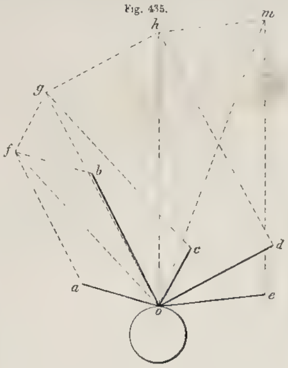
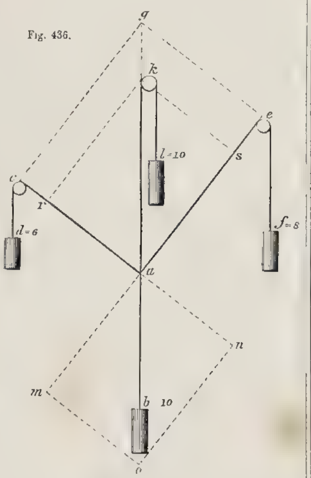
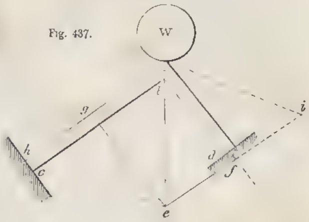


Fig. 436.



In the case of a load W (Fig. 437) pressing on the two inclined beams $b\ c$, $b\ d$, which abut respectively on the points c and d, it is obvious that the pressures will be in the directions $b\ c$, $b\ d$. To find the amounts of these pressures, draw the vertical line $b\ e$ through the centre of the load, and give it, by a scale of equal parts, as many units of length as there are units of weight in the load W: draw $e\ f$, $e\ g$ parallel to $c\ b$, $d\ b$; then $b\ g$, measured on the same scale, will give the amount of the pressure sustained by $b\ c$, and $b\ f$ the amount sustained by $b\ d$.

Fig. 437.

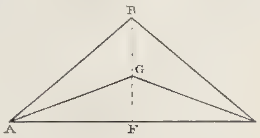


A slight consideration will serve to show that the amount of thrust, or pressure, is not influenced by the lengths of the pieces $b\ e$, $b\ d$. But it must be borne in mind, that although the pressure is not modified in its amount by the length, it is very much modified in its effects, these being greatest in the longest piece. Hence, great attention must be given to this in designing, lest by unequal yielding of the parts, the whole form of the assemblage be changed, and strains introduced which had not been contemplated.

If the direction of the beam $b\ d$ be changed to that shown by the dotted line $b\ i$, it will be seen that the pressures on both beams are very much increased, and the more obtuse the angle $i\ b\ h$ the greater the strain.

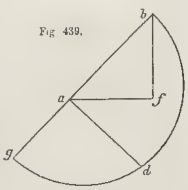
By this proposition we can compare the strength of roofs of different pitches.—Let A B, A G (Fig. 438) be rafters of roofs of the respective heights of F B, F G. Then, because the load on the rafter will increase in the same proportion as its length, the load on the rafter A B of the roof will be to the load of a similar covering on A F as A B to A F; but the action of the load on A B, by which it tends to break it, is to that on A F as A F to A B, consequently increased load on A B is diminished by its oblique action; and the diminished load on A F is increased by its direct action; and the transverse strain is the same in both. But the strength of beams, we have seen, is inversely as their length; therefore the power of A B to resist its strain is to the power of A F as A F to A B. If, therefore, a rafter A G is of a scantling just sufficient to carry its load, a rafter A B of a greater pitch would require to be made of a greater scantling, to enable it to carry the same load per foot of length. Hence, steep roofs must have stronger rafters than flat roofs to carry the same weight of covering per square yard of surface, or the rafters must be increased in number so as to reduce the load on each.

Fig. 438.



The increased size of scantling may be found geometrically as follows:—Let the line $a\ f$ (Fig. 439) be the depth of a beam that would carry the weight required if placed horizontally. Draw $f\ b$ perpendicular to $a\ f$, and make $a\ b$ equal to the slope or pitch of the rafter: produce $b\ a$, making $a\ g$ equal to $a\ f$, and draw the semicircle $g\ d\ b$. Then draw $a\ d$ perpendicular to $a\ b$, and $a\ d$ will be the depth required.

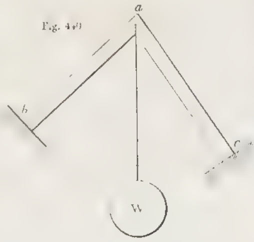
Fig. 439.



When the rafters of a roof are uniformly loaded,

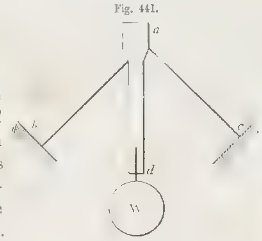
there is an angle which renders the oblique strain the least possible: this is when the tangent of the angle of inclination is ·7071, or the angle 35·16.

Fig. 440.



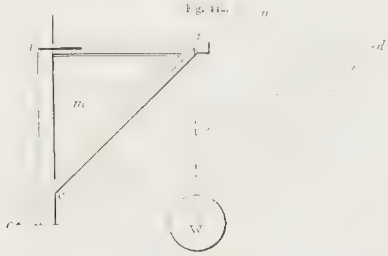
If, in place of the weight being superimposed on the beams, we suppose it suspended from their point of junction (Figs. 440 and 441), we obtain the strains in the same manner; and it is obvious that although the weight is suspended, the strains are still compressing the beams in the direction $a\ b$, $a\ c$; or, in other words, the beams act as struts. Substitute, in Fig. 441, for the string the piece of timber $a\ d$, and we have now the piece $a\ d$ stretched in the direction of its length and acting as a tie, and the other timbers compressed in the direction of their length.

Fig. 441.



It is very important to be able, in all cases, to discriminate between struts and ties; and we shall therefore illustrate this more at length. In the jib of the crane $b\ a\ c$

Fig. 442.

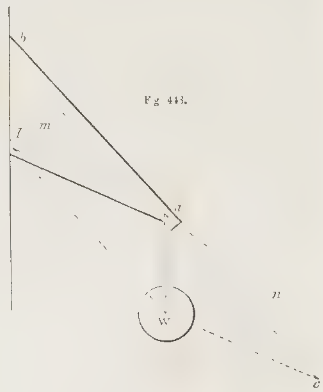


(Fig. 442), formed by the pieces $b\ a$, $c\ a$, we wish to find the measure and description of the strains exerted on these pieces when loaded by the weight W suspended from the point a. Produce $b\ a$ and $a\ c$ to d and e; make a W equal to the weight in equal parts; draw W d parallel to $c\ a$, and W e parallel to $b\ a$; then shall $a\ e$ be the strain on $a\ c$, and $a\ d$ the strain on $a\ b$. On attentively considering the figure, it will be seen that while $a\ c$ is sustaining a compressing strain, $b\ a$ is pulled in the direction of its length, and its place might be supplied by a rope. Now, change the directions of the pieces, as shown in the following figure (Fig. 443), and both pieces will appear to be in a state of tension; but it is not so; the place of $d\ a$ could not here be supplied by a rope; and it is therefore a strut, and not a tie.

The following is an invariable rule by which to discriminate between a strut and a tie in any system of framing:—

From the point where the weight or pressure acts, draw a line in the direction of the action of the pressure, and let the length of that line, measured on a scale of equal parts, denote the pressure in lbs., cwts., or tons. From the extremity opposite to the point on which the pressure is exerted, draw lines parallel to the pieces which sustain the strain. The line parallel to the one piece will necessarily cut the other piece, or its direction produced, within or without the framing. If the line cut the piece itself, or its direction produced within the framing, that piece is compressed — it is a strut; if it cut its direction produced beyond the framing, or point of pressure, the piece is in a state of tension—it is a tie. In the crane-jib $b\ a\ c$, Fig. 442, the line W e parallel to $a\ b$, cuts the direction of $a\ c$ produced within the framing; therefore $a\ c$ is, by the rule, a strut. The line W d, parallel to $c\ a$, cuts the direction of $b\ a$, produced in the point d without the framing—and consequently, by the rule, $b\ a$ is a tie.

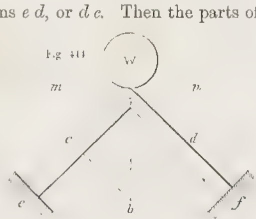
Fig. 443.



In like manner, in Fig. 443, W d cuts the piece $d\ a$ which is a strut, and W c cuts the direction of $b\ a$ produced in c without the framing; $b\ a$ is therefore a tie.

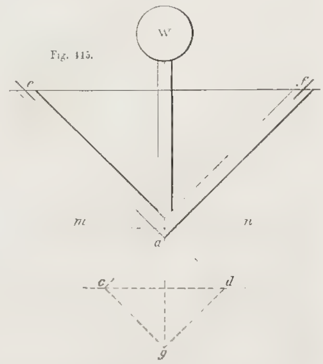
The following is another mode of doing the same thing:—Through the point a, in the two last figures, draw a straight line $m\ n$, parallel to the transverse diagonal of the parallelograms $e\ d$, or $d\ c$. Then the parts of the framing on that side of this line, to which the straining force would move if left at liberty, are in a state of compression, and the parts on the opposite side are in a state of tension.

Fig. 444.



In Fig. 444 the direction of the pressure is in the line $a\ b$: we set off from a to b, on a scale of equal parts, $a\ b$ equal to W, the weight, and draw from the point b, opposite to the point of pressure, the lines $b\ d$, $b\ c$ parallel to $e\ a$, $f\ a$, which, cutting the pieces $f\ a$, $e\ a$ in $d\ c$, show that they both act as struts.

Fig. 445.



In Fig. 445, let W be the weight acting on the point a:—from a draw $a\ g$ in the direction of the strain, and

make $a\,g$ equal to the weight: then, proceeding as before, we find that the parallels cut the directions of the pieces $e\,a$, $f\,a$ produced without the framing; and these pieces are therefore ties.

We have shown that the angles the pieces make with each other, influence materially the amount and proportion of the strains upon them. Generally, the strain on any piece is proportional to the sine of the angle which the straining force makes with the other piece directly, and to the sine of the angle which the pieces make with each other inversely. For, it is plain that the three pressures, A E, A F, and A G (Fig. 446), which are exerted at the point A, are in the proportions of the lines A E, A F, and F E (F E being equal to A G). But, because the sides of a triangle are proportional to the sines of the opposite angles, the strains are proportional to the sines of the angles A F E, A E F, and F A E. Therefore, to ascertain the strain on A B arising from any load A E acting in the direction A E; multiply A E by the sine of the angle E A G, and divide the product by the sine of B A C.

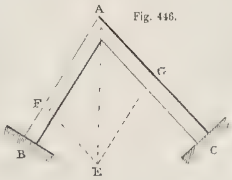


Fig. 446.

It is not necessary in practice to resort to calculation by sines. In designing framing, the measures of the strains can be obtained with equal accuracy by drawing the parallelogram of forces, and measuring from a scale of equal parts.

We have hitherto considered the pieces of timber themselves as being subjected to the strains; but it is obvious that they act also as transmitters of the pressures; and it is necessary to consider these as propagated to the points of support, which will be pressed or pulled by the same forces that act on the pieces serving as struts or ties. Thus we learn what supports must be provided for these points.

In the truss, Fig. 447, if A B represent the pressure on A in the direction A B, A C will be the strain on A E, and

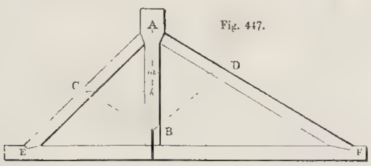


Fig. 447.

the magnitude of the pressure on E in the direction A E, and A D the pressure on the point F. The divellent force on the tie-beam E F will be equal to the sum of k C, m D, and the horizontal thrusts at E and F will be as k C, m D, respectively. Further, the pressure on the walls E and F will be unequal when the load A is not in the centre between them. In the figure, the pressure on E will be $=$ A k, and on F $=$ A m or k B.

We thus discover, also, what forces are exerted on the joints of the timber at E and F. For let E B (Fig. 448) be the end of the tie-beam E F, and A C the end of the rafter, the force in the direction of the rafter being represented by A C, then the vertical pressure on C will be equal to A B, and the thrust in the direction B E will be equal to B C; and this is the measure of the force acting to splinter off the part d.

In a queen-post roof, if the centre of the load A (Fig.

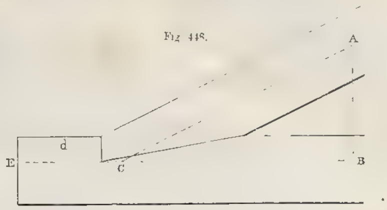


Fig. 448.

449) corresponds to the centre of the opening E F, the pressure on the points B and C should be alike, and may

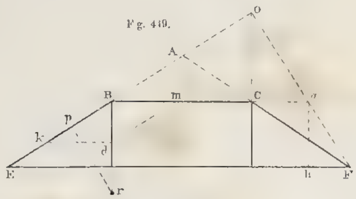


Fig. 449.

be found by making B d equal to the load on B, and drawing $d\,k$ and $m\,d$ parallel to B C and B E. Where the weight is not in the centre of the opening, but is in the vertical line O C; from a convenient point O in that vertical line, draw lines to the supporting points, and B g will be the length of the collar-beam, and $g\,h$ the place of the queen-post. To find the strains, make B r equal to the whole load, and draw $r\,p$ parallel to F O; the line $r\,p$ then represents the strain on g F, the other forces being as before.

STRENGTH AND STRAIN OF MATERIALS.

The materials employed in construction are exposed to certain forces, which tend to alter their molecular constitution, and to destroy that attraction which exists between their molecules, named cohesion. It is therefore necessary, in designing constructions, to be able to determine the relation which subsists between these destructive forces and the resistance which the various materials are susceptible of opposing to them.

The destructive forces in timber may operate in the manners following:—

I. By tension in the direction of the fibres of the wood, producing rupture by tearing it asunder.

II. By compression in the direction of the fibres, producing rupture by crushing.

III. By pressure at right angles to the direction of the fibres, or transverse strain, which breaks it across, and which, as will be seen, is a combination of the two former strains.

IV. By torsion or wrenching.

V. By tearing the fibres asunder.

It is to the three first of these only that attention need be directed, so far as concerns the work of the carpenter.

Every material resists with more or less energy, and for a longer or shorter period, these causes of destruction.

The resistance to the first-named force is called the resistance to extension, or simply, cohesion; to the second, the resistance to compression; and the third, the resistance to transverse force. The measures of these resistances are

the efforts necessary to produce rupture by extension, compression, or transverse strain.

Those materials which, when they have been submitted to a certain force less than the amount of their resistance, return to their normal condition when that force is withdrawn, are termed elastic. The knowledge of the elasticity proper to any body gives the means of calculating the amount of extension, compression, or flexure, which the body will sustain under a given force.

For the purposes of calculation, it is convenient to have a measure of the resilience or elastic power of a body expressed either in terms of its own substance, or in weight. This measure is termed the modulus of elasticity of the body.

If we suppose the body to have a square unit of surface, and to be by any force compressed to one-half or extended to double its original dimensions, this force is the modulus of the body's elasticity. No solid substance, it may at once be conceived, will admit of such an extent of compression or extension; but the expression for the modulus may nevertheless be obtained by calculation on the data afforded by experiment. The moduli for various kinds of woods will be found in the tables.

I. *Resistance to Tension.*

Although, mechanically considered, this is the simplest strain to which a body can be subjected, it is yet the one in regard to which fewest experiments have been made, in consequence of the great force required to tear asunder lengthways pieces of timber of even small dimensions. There is, too, a want of agreement sufficiently baffling in the results obtained by different operators. The results of the experiments made by Muschenbroek, Buffon, Barlow, Bevan, and others, are given in the following table, reduced to a section of one inch square:—

TABLE I.—*Tenacity of a square inch of different Woods, expressed in the weight in lbs., that will produce Rupture.*

	Names of Experimentalists.							
	Muschenbroek.	Rondelet.	Morin.	[illegible]	Barlow.	Bevan.	[illegible]	Mean Results.
Oak, English,	17,300	13,950	17,600	9,187	12,000 / 8,889	19,800	7,850	13,316
Elm,	13,489	.	14,788	[illegible]	...	14,400	6,070	14,226
Beech,	17,300	..	11,376	[illegible]	11,467	22,000		14,720
Ash,	12,000		17,064	12,406	17,207	...		14,670
Chestnut, Spanish,	...	13,300	.	.		10,500		11,900
Sycamore,	...					13,000	5,000	13,000
Poplar,	5,618		[illegible]			7,200	..	6,016
Alder,	14,186	.					4,290	14,186
Acacia,	20,582	..	.			16,000	...	18,291
Walnut,	8,130				.	7,800	5 360	8,465
Mahogany,	..			8,912	8,000	21,000 Old.	..	18,950
Teak,			15,642	12,922	15,090	8,200	.	12,460
Aspin,			6,990	...	...	...		6,990
Lance-wood,		..		...	..	23,400		23,400
Box,		.	19,908	19,850	19,890	...		19,892
Pear,			9,900		9,822	...		9,861
Larch,		10,220		..	...	8,900		9,560
Riga fir,					12,253	13,300	.	12,776
Petersburg,				.		13,300	...	13,300
Fir,	8,506			.	.	...	[illegible]	7,818
Pitch pine,	7,858	.				..	...	7,818
Cedar,	4,973				.	11,403	...	8,186
Norway pine,	.	7,287				14,300	.	10,293
Birch,		..	.	.		...	15,000	15,000
Hawthorn,			..			10,500		10,500
Hazel,			...			18,000		18,000
Holly,	.	.				16,000		16,000
Hornbeam,		.	.	...		20,240		20,240
Laburnum,		..			.	10,500		10,500
Lignum-vitæ,	11,800				.	..		11,800
Lime tree,	.	.	.		..	23,500	.	23,500
Maple,	..	.	.			10,584	..	10,584
Plane,	.	..	..	.	...	11,700	...	11,700
Willow,						14,000	.	14,000
Yew, Spanish		.	..	..		8,000	...	8,000

Although, on many considerations, it is not to be expected that experiments made on such small scantlings of timber as were used by the experimentalists above cited (some of these being only a square line in section), would agree with each other; yet the discrepancy is so great as to give little confidence in the results. Mr. Barlow, on mature consideration, has given the following table of the tenacity of wood usually employed by the carpenter; and subjoined is the mean result from the foregoing table, for the sake of contrast:—

TABLE II.—*Tenacity of a square inch of Timber in lbs.*

	Barlow's Mean Results.	Mean Results of Table No. I.
Oak,	10,000	13,316
Ash,	17,000	14,670
Beech,	11,500	14,720
Teak,	15,000	12,460
Mahogany,	8,000	18,950
Riga fir,	12,000	12,776

As Mr. Barlow's experiments were very carefully conducted, his table may be assumed as a safe guide.

1. As the strength of cohesion must be proportional to the number of fibres of the wood, or, in other words, to the area of the section, it follows that the tenacity of any piece of timber, or the weight which will tear it asunder lengthways, will be found by multiplying the number of square inches in its section by the tabular number corresponding to the kind of timber.

Example.—Suppose it is required to find the tenacity of a tie-beam of fir, of 8×6 inches scantling.

$8 \times 6 = 48$, which, multiplied by 12,000, the tabular number for fir, gives 576,000 lbs.

This is the absolute tenacity. Practically it is not considered safe to use more than one-fourth of this weight, or 144,000 lbs.

By the rule inverted, the section of the timber may be found when the weight is given, as follows:—

2. *Rule.*—Divide the given weight by the tabular number, and the quotient multiplied by 4 is the area of section required for the safe load.

Example.—Required the area of section of a piece of fir to resist safely a tensile strain of 144,000 lbs.

$$\frac{144000}{12000} = 12 \times 4 = 48, \text{ the section required.}$$

II. *Resistance of timber to compression in the direction of the length of its fibres.*

Experiments on this kind of resistance are not numerous.

Mr. Rennie found that to crush a cube of 1 inch on the side, the weights in lbs. required were, for—

African oak, ...	6,720 lbs.
English oak, ...	3,860 „
White deal, ...	1,928 „
American pine, ...	1,606 „
Elm, ...	1,284 „

M. Rondelet obtained higher results; that is, the timber experimented on by him presented a greater resistance. According to this author, a piece of timber diminishes in strength as it begins to bend; so that the mean strength of the wood of the oak, which is 44 lbs. French for every line superficial in the case of a cube, is reduced to 2 lbs. for a piece of the same wood, when its

height is 72 times its base. From a great number of experiments, he compiled the following progression:—

In a cube, the height of which is	1,	the strength is	1·
In a piece, the height of which is	12,	„	·833
„ „ „	24,	„	·5
„ „ „	36,	„	·33
„ „ „	48,	„	·166
„ „ „	60,	„	·083
„ „ „	72,	„	·041

Thus, in a cube of oak of 1 inch superficial of base, submitted to the action of a force pressing vertically, the mean force is expressed by 144 × 44 = 6336,	While the mean of experiments gave,	6,346
In a bar of the same wood of the same base, and 12 inches high, the strength by the progression would be 144 × 44 × ·833 = 5278, ...	„	5,310
In a bar 24 inches high, the strength by the formula, 144 × 44 × ·5 = 3168,	„	2,911
In a bar 36 inches, the strength by the formula, 144 × 44 × ·333 = 2110, ...	„	2,163

In a bar 48 = 144 × 44 × ·134 = 849.
In a bar 60 = 144 × 44 × ·083 = 526.
In a bar 72 = 144 × 44 × ·042 = 266.

In fir bars the following results were obtained:—

	By Calculation.	By Experiment.
In the cube of 1 inch, 144 × 52 × 1·	= 7,488	7,490
In the bar of 12 inches, „ × ·833	= 6,238	6,355
„ 24 „ „ × ·5	= 3,744	3,429
„ 36 „ „ × ·33	= 2,471	2,575

These results, M. Rondelet observes, accord with the experiments of MM. Perronnet, Lamblardie, and Girard.

In an experiment described by the latter, a piece of wood 2 metres 273 millemetres long, and 155 by 104 millemetres in section, broke under a weight of 33,120 kilogrammes.

Reducing these to English measures, the length is 7·35 feet, the sides of the base 6·05 and 4·06 inches respectively. The area of the section is therefore 24·5 inches, and as the weight is 72,864 lbs., the weight on the square inch is 2974 lbs.

The height of the piece is about twenty-two times the size of its base, and the progression would give a reduction of half the strength. If, therefore, 2974 is doubled, 5948 lbs. are obtained as the absolute resistance per square inch—a result which agrees very closely with the experiments of M. Rondelet.

The same author arrived at the following conclusions:—

1. That the resistance does not sensibly diminish in a prism, the height of which does not exceed eight times its base.

2. That when the height of the prism is ten times its base, it begins to yield by bending.

3. That when the height is 16 times the base, the piece of wood is incapable of resistance.

Tredgold says that when the length of the wood is less than eight times its diameter, the force causes it to expand in the middle of its length, and split into several pieces, but when it exceeds this length it yields by bending. As in practice the last case is almost the only one which occurs, we shall confine our observations to it alone.

As the first degree of flexure would prove fatal to any piece of framing, the strength necessary to resist this is what is required. According to Tredgold, the strain is directly as the weight, and inversely as the strength, which is inversely as the cube of the diameter in the case of a column. The strain is also directly as the square of the length, and inversely as the diameter, which is directly as the deflection. Therefore, for cylindrical posts he gives the formula $1{\cdot}7\, e \times L^2 \times W = D^4$, in which e is a constant number for the kind of timber (see p. 126).

When the post is rectangular, and D is its least side, $e \times L^2 \times W = B D^3$.

When the post is square, $4\, e \times L^2 \times W = D^4$, where D is the diagonal of the square.

The stiffest rectangular post is that in which the greater is to the less side as 10 to 6.

The equation is then $0{\cdot}6\, e \times L^2 \times W = D^4$.

When D is the least side, divide by 0·6 to find the greater.

These rules, expressed in words, are as follows:—

To find the diameter of a post that will sustain a given weight when the length exceeds ten times the diameter.

Rule.—Multiply the weight in lbs. by 1·7 times the value of e, then multiply the product by the square of the length in feet, and the fourth root of the last product will be the diameter in inches.

Examples.—1. The height of a cylindrical oak post being 10 feet, and the weight to be supported by it 10,000 lbs., required its diameter.

The tabular value of e for oak is ·0015—

$$\text{therefore, } 1{\cdot}7 \times {\cdot}0015 \times 100 \times 10000 = 2550,$$

the fourth root of which is 7·106, the diameter required.

By inverting the operation, we find the weight, when the dimensions are given, thus—The height of a cylindrical oak post being 10 feet, and its diameter 7·106 inches, required the weight it will support. The fourth power of 7 106 inches, as we have seen, is 2550, therefore—

$$\frac{2550}{1{\cdot}7 \times {\cdot}0015 \times 100} = \frac{2550}{{\cdot}255} = 10{,}000.$$

To find the scantling of a rectangular post to support a given weight.

Rule.—Multiply the weight in lbs. by the square of the length in feet, and the product by the tabular value of e. Divide this product by the breadth in inches, and the cube root of the quotient will be the thickness in inches.

2. Let the height of the post, as before, be 10 feet, and the weight to be supported 10,000 lbs., required the thickness of the post when its breadth is 5 inches.

$$\frac{{\cdot}0015 \times 10^2 \times 10000}{5} = 300,$$

the cube root of which is 6 69, therefore the section of the post is 6·69 × 5 inches.

To find the dimensions of a square post that will sustain a given weight.

Rule.—Multiply the weight in lbs. by the square of the length in feet, and the product by four times the value of e, and the fourth root of the product will be the *diagonal* of the post in inches.

3. Let a square oak post be 10 feet long, and let the weight to be supported be 10,000 lbs., required the dimensions of its sides. The value of e is ·0015—

$$\text{therefore, } {\cdot}0015 \times 4 \times 100 \times 10000 = 6000,$$

the fourth power of the diagonal of the square, therefore the diagonal of the square is 8·8 inches, and its side 6·22.

To find the stiffest rectangular post that will support a given weight.

Rule.—Multiply the weight in lbs. by 0·6 times the tabular value of e; multiply the product by the square of

the length in feet; the fourth root of this product will be the least side in inches. Divide this by 0·6 for the greatest side.

4. Let the length of the stiffest rectangular oak post be 10 feet, and the weight to be supported 10,000 lbs., required the side of the post.

$$0·6 \times ·0015 \times 10 \times 10 \times 10000 = 9000,$$

the fourth root of which is 5·477, the least side, which, divided by 0·6, gives 9·13 as the greatest side.

From experiments made by Lamande and Girard, by loading posts till a small amount of deflection was visible, and thus ascertaining the values of l W D, Mr. Tredgold calculated the value of the constant e, so as to give the load to which the post might be safely exposed. These constants for different woods are found in the following table:—

TABLE III.—*Constant Numbers, to be used in calculating the Dimensions of Posts, Pillars, &c., of Timber, pressed in the direction of their Lengths.*

Kind of Wood.	Value of the Constant e
English oak	·0015
Beech,	·00195
Ash,	·00168
Elm,	·00184
Spanish mahogany,	·00205
Honduras do.	·00161
Teak,	·00118
Riga fir,	·00152
Memel ditto,	·00133
Norway spruce,	·00142
Larch,	·0019

III. *Resistance of timbers to transverse strain.*

When a piece of timber is fixed horizontally at its two ends, then, either by its own proper weight, or by the addition of a load, it bends, and its fibres become curved. If the curvature do not exceed a certain limit, the timber may recover its straightness when the weight is removed; but if it exceed that limit, although the curvature diminishes on the removal of the load, the timber never recovers its straightness, its elasticity is lessened, and its strength is partly lost. On the load being augmented by successive additions of weights, the curvature increases until rupture is produced. Some woods, however, break without previously exhibiting any sensible curvature.

It may be supposed that, in the case of the timber being exactly prismatic in form, and homogeneous in structure, the rupture of its fibres would take place in the middle of its length, in the vertical line, where the curves of the fibres attain their maxima.

In the rupture by transverse strain of elastic bodies in general, and consequently in wood, all the fibres are not affected in the same manner. Suppose a piece of timber, composed of a great number of horizontal ligneous layers, subjected to such a load as will bend it, then it will be seen that the layers in the upper part are contracted, and those in the lower part extended, while between these there is a layer which suffers neither compression nor tension; this is called the neutral plane or axis.

If the position of the neutral axis could be determined with precision, it would render more exact the means of calculating transverse strains; but as the knowledge of the ratios of extensibility and compressibility is not exact, the position of the neutral axis can only be vaguely deduced from experiment. Were the ratios of compression and extension equal, the neutral axis would be in the centre of the beam; but experiments show that this equality does not exist. Barlow found that in a rectangular fir beam the neutral axis was at about five-eighths of the depth;* and Duhamel cut beams one-third, and one-half, and two-thirds through, inserting in the cuts slips of harder wood, and found the weights borne by the uncut and cut beams to be as follows:—

Uncut Beam.	One-third Cut.	One half Cut.	Two-thirds Cut.
45 lbs.	51 lbs.	48 lbs.	42.

Results which clearly show, that less than half the fibres were engaged in resisting extension; and it has been long known that a beam of soft wood, supported at its extremities, may have a saw-cut made in the centre, half-way through its thickness, and a hard wood piece inserted in the cut, without its strength being materially impaired.

It is not here necessary to enter into an investigation of the theory of transverse strain. The results of it, corrected by experimental evidence on which rules of practical utility may be founded, are all that need be sought for.

The transverse strength of beams is—

Directly as the breadth,
Directly as the square of the depth, and
Inversely as the length;
or substituting the letter b for the breadth,
d for the depth, and
l for the length,

and placing the ratios together, the general expression of the relation of strength to the dimensions of a beam is obtained as follows:—

$$\frac{b \times d^2}{l}.$$

But this forms no rule for application, since beams of different materials do not break by the application of the same load; and it is therefore necessary to find by experiment a quantity to express the specific strength of each material.

Let this quantity be represented by S, and the formula becomes—

$$\frac{b \times d^2 \times S}{l} = \text{breaking weight.}$$

By this formula experiments can be reduced so as to give the value of S. It is only necessary to find the breaking weight of a beam whose dimensions are known, and then by transposition of the equation—

$$\frac{l \times \text{breaking weight}}{b \times d^2} = S.$$

S thus becomes a constant for all beams of the same material as the experimental beam.

Although this ratio of strength to the dimensions of the beam is very nearly correct, it is not absolutely so; and the French writers modify it in the manner which will be stated subsequently. The length of a beam appears to

* Mr. Barlow's method of operating was as follows:—He ran a saw cut to 5-8ths of the depth of the beam, and inserted a thin slip of pear tree, sufficiently tight to preserve the stiffness of the beam, but not so tight as to cripple it. The beam was then loaded till it broke. On examining the slip of pear-tree after the fracture of the beam, the impression of the fibres was found distinctly marked on it, strongest at top, and weakening gradually to the bottom, where compression ceased.

influence the strength to a greater extent than the theory allows; for similar beams are rather more than twice as strong when half as long, and the strength does not increase quite so rapidly as the square of the depth.

When the value of S for various kinds of wood is determined, the formula may be used for computing the strength of a given beam, or the size of a beam to carry a given load. For any three of the quantities, l, b, d, W, being given, we can find the fourth thus:—

I. When the beam is fixed at one end and loaded at the other, and when

$$\frac{l\,W}{b\,d^2} = S.$$

The length, breadth, and depth being given, to find the weight— $$W = \frac{S\,b\,d^2}{l}.$$

The weight, breadth, and depth being given, to find the length— $$l = \frac{S\,b\,d^2}{W}.$$

The weight, length, and depth being given, to find the breadth— $$b = \frac{l\,W}{S\,d^2}.$$

The weight, length, and breadth being given, to find the depth— $$d = \sqrt{\frac{l\,W}{b\,S}}.$$

When the section of a beam is square, that is, when $b = d$; then b or $d = \sqrt[3]{\frac{l\,W}{S}}$.

II. When the beam is supported at one end, and loaded in the middle; then $\frac{l\,W}{4\,b\,d^2} = S$, and we have for the former cases—

$$W = \frac{4\,b\,d^2\,S}{l}; \quad l = \frac{4\,b\,d^2\,S}{W}; \quad b = \frac{l\,W}{4\,d^2\,S};$$

$$d = \sqrt{\frac{l\,W}{4\,b\,S}}; \text{ and where } b = d,\ b \text{ or } d = \sqrt[3]{\frac{l\,W}{4\,S}}.$$

III. When the beam is fixed at both ends—

When loaded in the Middle.	When loaded at an Intermediate Point.
$W = \frac{6\,b\,d^2\,S}{l}$;	$W = \frac{3\,l\,b\,d^2\,S}{2\,m\,n}$;
$l = \frac{6\,b\,d^2\,S}{W}$;	$l = \frac{2\,m\,n\,W}{3\,b\,d^2\,S}$;
$b = \frac{l\,W}{6\,d^2\,S}$;	$b = \frac{2\,m\,n\,W}{3\,l\,d^2\,S}$;
$d = \sqrt{\frac{l\,W}{6\,b\,S}}$;	$d = \sqrt{\frac{2\,m\,n\,W}{3\,l\,b\,S}}$;
$d = b = \sqrt[3]{\frac{l\,W}{6\,S}}$.	$d = b = \sqrt[3]{\frac{2\,m\,n\,W}{3\,l\,S}}$.

Where $m\,n$ is the rectangle of the segments into which the load divides the beam.

IV. When the beam is supported at both ends, but not fixed—

When load is uniformly diffused.	When loaded at an intermediate point.
$W = \frac{2\,b\,d^2\,S}{l}$;	$W = \frac{l\,b\,d^2\,S}{m\,n}$;
$l = \frac{2\,b\,d^2\,S}{W}$;	$l = \frac{m\,n\,W}{b\,d^2\,S}$;
$b = \frac{l\,W}{2\,b\,d^2}$;	$b = \frac{m\,n\,W}{l\,d^2\,S}$;
$d = \sqrt{\frac{l\,W}{2\,b\,S}}$;	$l = \sqrt{\frac{m\,n\,W}{l\,b\,S}}$;
$b = d = \sqrt[3]{\frac{l\,W}{2\,S}}$.	$d = b = \sqrt[3]{\frac{m\,n\,W}{l\,S}}$.

When the beam is inclined, the *horizontal* distance between its supports is the length or l.

The following table contains the results of experiments made by Mr. Barlow on the transverse strength of various kinds of wood, with the value of S, calculated according to the formula $S = \frac{l\,W}{4\,b\,d^2}$:—

TABLE IV.

1. Name of Woods.	2. Length in feet	3. Breadth in inches	4. Depth in inches.	5. Specific Gravity, water being 1000.	6. Greatest Weight, while elasticity remained perfect.	7. Breaking Weight in lbs.	8. Value of S, $S = \frac{l\,W}{4\,b\,d^2}$.	9. Value of C, $C = \frac{l\,W}{b\,d^2}$.	10. Number of Experiments	11. Remarks.
Acacia, ...	4·16	2	2	710	...	[illegible]	1567	621	1	..
Ash, ...	4·16	2	2	727	...	1304	..	.	...	Middle.
,, ...	..		.	702	.	1304	2037	679		Outside
,, ...	7	2	2	760	225	772	2026	675	3	...
Beech, ...	7	2	2	696	150	593	1556	552	..	.
Birch, Common, . .	4·16	2	2	792	...	1164	1820	607	...	Middle
,, ,, . . .	.	...	...	630	...	1304	2037	679	..	Outside
,, ,, .	4·06	2	2	648	...	[illegible]	1785	595	2	Middle
,, Black American	.	.	...	651	...	1174	1834	605	2	Outside
Bullet tree, ...	4·16	2	2	1029		1696	2646	882	2	...
Deal, Christiana, ...	4·16	2	2	689	...	996	1562	521	2	..
,, Memel, ...	4·16	2	2	590	...	1108	1731	577	2	...
Elm, ...	4·16	2	2	543	..	714	1115	372	2	...
Fir, New England, ...	7	2	2	553	150	420	1102	367	3	..
,, Riga, ...	7	2	2	753	125	422	1108	369	3	..
,, ,, ...	6	2	2	738	150	467	1051	350	3	...
,, Mar Forest, ...	7	2	2	696	125	456	1144	380	3	...
,, ,, .	6	2	2	698	150	561	1262	420	6	...
Greenheart, ...	4·16	2	2	1000	.	...	1752	584	2	. .
Larch, ...	7	2	2	531	125	325	853	284	3	...
,, ...	6	2	2	445	142	447	1036	345	9	.
Norway spar, ...	6	2	2	577	200	655	1474	491	3	. .
Oak, English, ...	7	2	2	969	[illegible]	450	1181	[illegible]	3	...
,, ,, ...	6	2	2	954	200	637	1672	557	3	...
,, Canadian, ...	7	2	2	872	225	673	1766	588	3	...
,, Danzic, ...	7	2	2	756	200	560	1457	485	3	...
,, Adriatic, ...	7	2	2	993	150	526	1383	448	3	...
,, English, ...	4·16	2	2	903	...	999	1561	...	1	Fast grown.
,, ,, .. .	. .	..	...	856	...	677	1058	.	1	Slow grown.
,, ,, .. .	...	.		972	...	[illegible]	1561	...	1	Fast grown.
,, ...	..	...	.	835	...	943	1473	...	1	Slow grown.
,, ,, .. .	..	...	...	748	..	1447	2261	...	1	In store 2 years.
,, ,, ...	...	...	..	756	...	1304	2037 (Mean, 1658.)	Mean 553	6	In store 16 years
Pitch pine, ...	7	2	2	660	150	622	1632	544	3	...
Poon, ...	7	2	2	579	[illegible]	846	2221	740	3	...
Red pine, ...	7	2	2	657	150	511	1341	447	3	...
Teak, ...	7	2	2	745	300	958	2462	820	3	...

In using Mr. Barlow's formulæ for transverse strength, the eighth column of the table gives the constants S for the various kinds of timber; and all the dimensions of the timber must be in inches. The rules for two of the cases, expressed in words, are as follows:—

To find the strength of a rectangular beam, fixed at one end and loaded at the other.

Rule.—Multiply the value of S by the area of the section, and by the depth of the beam, and divide the product by the length in inches. The quotient will be the breaking weight in lbs.

Example.—A beam of Riga fir projects 10 feet beyond its point of support, and its section is 8 × 6 inches, what is its breaking weight?

Area 8 × 6 = 48, multiplied by the depth 8 = 384. Multiply this by the constant 1108, and divide the product by the length, $\frac{1108 \times 384}{120} = 3545$ lbs. The fourth part of this is the safe weight to impose in practice, therefore—

$$\frac{3545}{4} = 886 \text{ lbs.}$$

To find the strength of a rectangular beam, when it is supported at the ends and loaded at the middle.

Rule.—Multiply S by four times the depth, and by the area of the section in inches, and divide the product by the length between the supports in inches, and the quotient will be the greatest weight the beam will bear in lbs.

Example.—A beam of Riga fir is 20 feet long between

its supports, and its section is 8 × 6 inches; required its breaking weight.

$$\frac{1108 \times 8 \times 4 \times 8 \times 6}{240} = 7091{\cdot}2.$$

The fourth part of this is the safe load, therefore—

$$\frac{7091}{4} = 1772 \text{ lbs.}$$

The constant C, in the same table, column 9, and in column 11 of Table VIII., is for the formulæ as given by Mr. Tredgold, in which it is not necessary to convert the length of the bearing into inches.

When the beam is supported at one end, and loaded at the other, the equation is $\frac{b\,d^2\,C}{4\,l}$ = breaking weight.

Or, in words, as follows:—Multiply the breadth in inches by the square of the depth in inches, and by the constant C for the kind of timber; and divide the product by four times the length in feet, for the breaking weight.

Example.—A beam of Riga fir projects 10 feet beyond its point of support, and is 8 × 6 inches in section; required its breaking weight.

The value of C for Riga fir is 369, therefore—

$$\frac{369 \times 6 \times 64}{40} = 3542{\cdot}4 = \text{the breaking weight.}$$

$$\frac{3542}{4} = 885 = \text{safe weight.}$$

When the beam is supported at both ends, and loaded in the middle.

Rule.—Multiply the breadth by the square of the depth, and by C, and divide by twice the length; the quotient is the breaking weight.

Example.—Let the beam be 8 × 6 in section, and 20 feet long between its supports; required the breaking weight.

$$\frac{369 \times 6 \times 64}{20} = 7084.$$

In the summary of formulæ in the sequel (p. 130), will be found all the rules written in words.

It has been stated that some French writers use formulæ different from those here given, and intended to unite more closely the results of theory and experiment; but they are difficult of application in practice, and the results vary so little from those of the formulæ given, that the correction is not worth making.

Mr. Gwilt, in his *Encyclopædia of Architecture,* not only ignores all the laborious experiments that have been made in this country, but also speaks disparagingly of the labours of the able men who have endeavoured to benefit the architect and engineer by bringing the aid of mathematical investigation to found upon those experiments safe and general rules for practice. Mr. Gwilt cites Buffon's experiments, as given by Rondelet, and in his introductory notice of them says, "They are worth more than all which has hitherto been done in this country. The treatises on mechanical carpentry seem to have been written more with the view of perplexing than of assisting the student." And this, too, notwithstanding the labours of Robison, Young, Barlow, Tredgold, Hodgkinson, Bevan, Rennie, and a host of others.

But a little investigation would have made it apparent that the constants derived by these writers from their experiments give results most singularly in accordance with those obtained by the able French philosopher; and, which is of greater importance, perfectly safe when applied in practice.

The discrepancy between the results of the English formulæ here given and the experiments of Buffon occurs chiefly in short bearings; and as the strength obtained by the formulæ is sufficient for long bearings, it follows that it must be sufficient also for the short lengths, erring only in being slightly in excess, or "a little stronger than strong enough."

The rule given by Rondelet is expressed in terms of only two of the three dimensions of the timber, and requires a constant which is empirical, like that of the formulæ already given. It is as follows:—

Subtract from the primitive strength one-third of the quantity which expresses the number of times the depth is contained in the length of the beam.

Multiply the remainder by the square of the length.

Divide the product by the number that expresses the relation of the depth to the length.

In the following table, the four first columns give the result of certain of Buffon's experiments, reduced to English measures: the two other columns contain constants for Barlow's and Tredgold's formulæ, calculated from the other columns:—

TABLE V.—*Results of certain of M. Buffon's Experiments on Transverse Strength.*

No	Length.	Side of Square.	Mean Weight which brake the pieces.	Breaking Weight by Rondelet's Formula.	Value of S, $S = \frac{l\,W}{[illegible]}$	Value of C, $C = \frac{l\,W}{[illegible]}$
1.	7·462	4·264	5,768	5,768	1670	546
	8·528	...	4,869	4,943	1612	538
	9·594	...	4,387	4,301	1635	545
	10·660	...	3,946	3,799	1644	548
	12·792	...	3,279	3,018	1623	541
	7·462	5·33	12,496	12,496	1847	616
	8·528	...	10,626	10,750	1800	600
	9·594	...	8,635	9,429	1440	480
	10·660	...	7,765	8,357	1441	480
	12·792	...	6,644	6,748	1678·5	559
	14·924	..	5,819	4,600	1730	577
	17·096	.	4,810	4,738	1620	540
	19·188	.	4,120	4,066	1500	500
	21·320	..	3,624	3,530	1531	510
	23·452	...	3,364	3,092	1563	521
	25·584	..	2,502	2,726	1260	420
	29·848	..	2,112	2,151	1247	412
	7·462	6·396	20,635	19,196	1654	554
	8·528	...	16,804	16,562	1637	545
	9·594	.	14,292	14,547	2011	670
	10·660	...	12,197	12,877	1560	[illegible]
	12·792	...	9,938	9,420	1446	482
	14·924	...	8,210	8,666	1400	466
	17·056	..	7,030	7,348	1365	442
	19·188	...	6,187	6,319	1300	434
	21·320	...	5,495	5,506	1337	446
	10·660	8·528	30,148	30,363	1828	609
	12·792	..	25,540	24,883	1804	601
	14·924	...	21,605	20,854	1843	614
	17·056	...	17,968	17,833	1740	580
	19·188	...	14,577	15,482	1587	529
	21·320	..	13,303	13,593	1570	523
				Average...	... 1621 ..	... 540

The constants S and C agree very nearly with those derived from the experiments of Mr. Barlow and Mr. Tredgold: the latter assumes 550 as the value of S.

In any beam exposed to transverse strain, it is manifest that there must be some certain proportion between the breadth and depth which will afford the best results. It is found that this is obtained when the breadth is to the depth as 6 to 10. Therefore, when it is required to find the least breadth that a beam for a given bearing should have, the formula is as follows:—

$$\frac{l}{\sqrt{d}}\;0{\cdot}6 = b;$$

or, expressed in words—

Rule.—Divide the length in feet by the square root of the depth in inches, and the quotient, multiplied by the decimal 0·6, will give the least breadth the beam ought to have.

The nearer a beam approaches to the section given by this rule, the stronger it will be; and from this rule is derived the next.

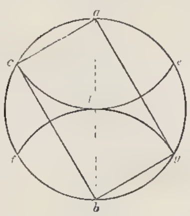
To find the strongest form of a beam so as to use only a given quantity of timber.

Rule.—Multiply the length in feet by the decimal 0·6, and divide the given area in inches by the product, and the square of the quotient will be the depth in inches.

Example.—Let the given length be 20 feet, and the given area of section 60 inches. Then $\frac{60}{20 \times 0{\cdot}6} = 5{\cdot}00$, the square of which is 25 inches, the depth required, and the breadth is consequently 2·4 inches.

The *stiffest* beam is that in which the breadth is to the depth as ·58 to 1. The stiffest beam which can be cut out of a round tree may be found graphically as follows:—Let $a\ b$ (Fig. 450) be the diameter of the circle, then with a radius equal to the radius of the circle, and from the extremities of the diameter, draw the arcs $c\ d\ e$, $f\ d\ g$; join $a\ c$, $c\ b$, $b\ d$, $d\ a$, and the parallelogram thus formed is the section of the stiffest beam which can be cut from the tree. The French writers make the ratio of breadth to depth as 5 : 7.

Fig. 450.



It will be seen by the formulæ that there is an unquestionable advantage obtained by fixing the ends of bearing timbers, as the increase of strength is then as 3 to 2. This, although not easily accomplished, nor indeed proper when the ends of the timbers are built into walls, as the stability of these may be injured, yet may be done in certain circumstances; and it further leads to important practical rules. The chief of these is, that girders and joists, and all bearing timbers whatever, when laid over several points of support, should be made as long as possible; and that purlins, rafters, and joists should, whenever the space will admit of it, be notched on the supports, in place of being framed between them.

But the breaking weight of a beam has seldom, for practical purposes, to be ascertained. For when a beam is loaded, and even by the effort of its own weight, when its length is great compared with its other dimensions, it sinks down or bends in the middle. If the deflection produced by a load does not exceed a certain limit, the timber will recover its straightness when the load is removed; but beyond that limit, the elasticity of the fibres becomes diminished; the timber loses part of its strength, and the addition of weight at length causes rupture of the fibres.

Mr. Barlow gives one-fourth of the breaking weight as the greatest weight that should be used; but experiment shows that one-fifth of the breaking weight produces a permanent set in a beam, and consequently a diminution of its strength; and the French authors invariably give only one-tenth of the breaking weight as the safe load when the load is fixed; but if a moving load has to be provided for, they say that it should not exceed one-twelfth or one-thirteenth of the breaking weight.

But the load which a beam may sustain without permanent injury, may cause such an amount of deflection as to unfit it for the purposes of the carpenter; for a beam, forming part of a system of framing, cannot be deflected without a sensible alteration of its length, and thus the framing becomes deranged. Moreover, in girders, beams, and joists which sustain floors and ceilings, where the work should not only be true, but appear true, a very small amount of curvature would mar its beauty. Mr. Tredgold assumes that this curvature is not sensible when it does not exceed the $\frac{1}{240}$th part of the length of the beam; and in forming his rules, he has taken the fortieth part of an inch in every foot as the allowable deflection.

The term stiffness is opposed to flexibility: thus, when a piece of timber bends under a weight in a very small degree, it is said to be stiff; and when it bends considerably, it is said to be flexible. Now, the stiffness of beams is proportional to the space they are bent through by a given weight when the lengths are the same, but that two pieces of different lengths may be equally stiff, the deflection should be proportional to their lengths. For a deflection which would not be injurious in a beam 40 feet long, would be highly detrimental in one 10 feet long.

The extension of any part of a beam is directly as the force that produces it, and as it is known by experiment that the deflection is as the weight, all other things being the same, the deflection is therefore as the extension.

The extension is as the weight and the cube of the length directly, and as the breadth and cube of the depth inversely: the deflection will consequently be in the same proportion. If L be the length in feet; W, the weight in lbs.; B, the breadth in inches; and D, the depth in inches; $\frac{L^3 \times W}{B \times D^3}$ is as the deflection.

In order that a beam may be equally stiff, as we have seen above, the deflection should be inversely as the length: consequently, the weight that a beam will sustain will be $\frac{B \times D^3}{d \times L^2} = W$, where d is the deflection in inches; and $\frac{L^2 \times W}{B \times D^3\ d} =$ a constant number for the same kind of timber.

But, before these rules can be applied, it is necessary to obtain, experimentally, the value of d. This being done, we should have $\frac{B \times D^3 \times d}{L^3 \times W} =$ a constant quantity; which being given, the deflection in any other case may be found.

Experiments, with the view of determining this constant, have been made by various writers. Of these, probably, the most satisfactory were by Duhamel; for this reason, that the scantlings operated on were of the size generally used in building. From these and other experiments, many of which were made by himself, Mr. Tredgold computed the constants for the various kinds of timber given in the following table.

In computing the value of a, Mr. Tredgold assumed the deflection to be $\frac{1}{40}$th of an inch per foot; and the formula became $\frac{B \times D^3}{L^2 \times W} = a$. When the deflection is required to be less than this, say $\frac{1}{2}$ of $\frac{1}{40}$, then multiply the constant a by 2; if $\frac{1}{3}$ of $\frac{1}{40}$, multiply a by 3; or if required greater than $\frac{1}{40}$, multiply a by any number of times that the deflection may exceed $\frac{1}{40}$th of an inch per foot.

Table VI.—*Table of the Values of "a."*

	Value of a
Oak, old, ...	·0099
„ young, ...	·0105
„ „ ...	·0164
„ „	·0197
„ Riga, ...	·0107
„ English, ...	·0119
„ Canadian, ...	·0090
„ Adriatic,	·0193
Danzic ...	·0105
	9) ·1119
Mean, ...	·0124
Mean of 10 examples of English oak, ...	·0124
White spruce, ...	·00957
„ „	·0138

To find the scantling of a piece of timber which, when laid in a horizontal position, and supported at both ends, will resist a given transverse strain, with a deflection not exceeding $\frac{1}{40}$th of an inch per foot.

1. *When the breadth and length are given, to find the depth.*

Rule.—Multiply the square of the length in feet by the weight to be sustained in lbs., and the product by the tabular number a (Table VI.; and column 10, Table VIII.); divide the product by the breadth in inches, and the cube root of the quotient will be the depth in inches.

Example.—Required the depth of a pitch pine-beam, having a bearing of 20 feet, and a breadth of 6 inches, to sustain a weight of 1000 lbs.

The square of the length, 20 feet	=	400
Multiplied by the weight .	=	1000
And the product		400,000
By the decimal		·016
Divide the product by the breadth, 6 inches	=	6400·000
Gives		1066·666

The cube root of which is 10·2 inches, the depth required.

2. *When the depth is given.*

Rule.—Multiply the square of the length in feet by the weight in lbs., and multiply this product by the tabular value of a: divide the last product by the cube of the depth in inches, and the quotient will be the breadth required.

Example.—Length of pitch-pine beam 20 feet; depth, 10·2 inches; weight, 1000 lbs.

Then $\dfrac{20 \times 20 \times 1000 \times ·016}{10·2 \times 10·2 \times 10·2} = \dfrac{6400}{1061} = 6$, the breadth required.

3. *When neither the breadth nor the depth is given, but they are to be determined by the proportion before given, that is, breadth to depth as* 0·6 *to* 1.

Rule.—Multiply the weight in lbs. by the tabular number a, and divide the product by 0·6, and extract the square root: multiply the root by the length in feet, and extract the square root of this product, which will be the depth in inches, and the breadth will be equal to the depth multiplied by 0·6.

Example.—Weight, 1000 lbs.; value of a, ·016; length, 20 feet. $\sqrt{\dfrac{1000 \times ·016}{0·6}} \times 20 = 106.$

$\sqrt{106} = 10·2$, the depth required; then $10·2 \times 0·6 = 6·0$, the breadth required.

The following are the formulæ given by Mr. Barlow:—

B = the breadth, D = the depth, L = the length, W = the weight, and d = the deflection.

When the beam is supported at one end.

1. *Where the weight is at the extremity, the breadth, length, and amount of deflection being given, to find the depth.*

$$\sqrt{\frac{\mathrm{W}}{\mathrm{E\,B}\,d}} \times \mathrm{L} = \mathrm{D}.$$

(The length in feet, the breadth, depth, and deflection in inches.)

2. *Where the weight is uniformly spread, the breadth, length, and deflection being given, to find the depth.*

$$\sqrt{\frac{3·375\ \mathrm{W}}{\mathrm{E\,B}\,d}} \times \mathrm{L} = d.$$

(The length in feet, the breadth, depth, and deflection in inches.)

And when the beam is a cylinder, and the weight at its end, the deflection will be 1·7 times that of a square beam.

When the beam is supported at both ends, and the length, weight, and deflection given.

The weight being in the middle.	The weight uniformly spread.
$\dfrac{\mathrm{W}\,l^3}{16\,\mathrm{E}\,d} = \mathrm{B\,D}^3.$	$\dfrac{·625\ \mathrm{W\,L}^3}{16\,e\,d} = b\,d^3.$

(The length in feet, the breadth, depth, and deflection in inches.)

And in a square beam—

$\dfrac{\mathrm{W\,L}^3}{16\,\mathrm{E}\,d} = \mathrm{B}^4 = \mathrm{D}^4.$ $\qquad \dfrac{·625\ \mathrm{W\,L}^3}{16\,\mathrm{E}\,d} = \mathrm{B}^4 = \mathrm{D}^4$

When the beam is a cylinder.

Multiply the quotient by 1·7, and the fourth root of the product is the diameter.

Table VII.—*Table of the Value of* E *in the above Formulæ.*

CALCULATED.

Ash, ...	E =	·244	
Beech, ...	„	·195	
Birch, ...	„	·240	
American ditto, ...	„	·256	
Deal, Christiana, ...	„	·230, ·115	
Deal, Memel, ...	„	·190	
Elm, ...	„	·101	
Fir, New England, ...	„	·317	
Fir, Riga, ...	„	·167	
Fir, Mar Forest, ...	„	·94	
Greenheart, ...	„	·384	
Larch, ...	„	·91	Mean, ·120.
Do., ...	„	·152	
Do., ...	„	·119	
Norway Spar, ...	„	·211	
Oak, English, ...	„	·210	
Oak, Canadian, ...	„	·310	
Oak, Danzig, ...	„	·149	
Oak, Adriatic, ...	„	·142	
Pitch pine, ...	„	·177	
Red pine, ...	„	·272	
Teak, ...	„	·349	

Summary of Rules.

I. *Resistance to Tension or Tenacity.*

To find the tenacity of a piece of timber.

1. *Rule*—Multiply the number of square inches in its section by the tabular number corresponding to the kind of timber (Table I.; or column 4, Table VIII.).

To find the area of section when the weight is given.

2. *Rule.*—Divide the given weight by the tabular number, and multiply the quotient by 4 for the area of section required for the safe load.

II. *Resistance to Compression.*

It is not necessary to give rules for the absolute crushing force of timber. Those that follow are applicable to the cases of posts whose length exceeds ten times their diameter, and which yield by bending.

To find the diameter of a post that will sustain a given weight.

3. *Rule.*—Multiply the weight in lbs. by 1·7 times the value of e (Table III.; or column 9, Table VIII.); then multiply the product by the length in feet, and the fourth root of the last product is the diameter in inches required.

To find the scantling of a rectangular post to sustain a given weight.

4. *Rule.*—Multiply the weight in lbs. by the square of the length in feet, and the product by the value of e: divide this product by the breadth in inches, and the cube root of the quotient will be the depth in inches.

To find the dimensions of a square post that will sustain a given weight.

5. *Rule.*—Multiply the weight in lbs. by the square of the length in feet, and the product by 4 times the value of e; and the fourth root of this product will be the *diagonal* of the post in inches.

To find the stiffest rectangular post to sustain a given weight.

6. *Rule.*—Multiply the weight in lbs. by 0·6 times the tabular value of e, and the product by the square of the length in feet; and the fourth root of this product will be the least side in inches: divide the least side by 0·6 to obtain the greatest side.

III. *Resistance to Transverse Strain.*

1st. When the beam is fixed at one end and loaded at the other.

To find the breaking weight, when the length, breadth, and depth are given.

7. *Rule.*—Multiply the square of the depth in inches by the breadth in inches, and the product by the tabular value of S (Table V.; or column 12, Table VIII.), and divide by the length in inches: the quotient is the breaking weight.

To find the length, when the breadth, depth, and breaking weight are given.

8. *Rule.*—Multiply the square of the depth by the breadth, and by the value of S, and divide by the weight: the quotient is the length.

To find the breadth, when the depth, length, and breaking weight are given.

9. *Rule.*—Multiply the weight by the length in inches, and divide by the square of the depth in inches multiplied by the value of S: the quotient is the breadth.

To find the depth, when the breadth, length, and weight are given.

10. *Rule.*—Multiply the length in inches by the weight, divide the product by the breadth in inches multiplied by S, and the square root of the quotient is the depth.

To find the side of a square beam, when the length and weight are given.

11. *Rule.*—Multiply the length in inches by the weight, divide the product by S, and the cube root of the quotient is the side of the square section.

2d. When the beam is *supported* at one end and loaded in the middle.

The length, breadth, and depth, all in inches, being given, to find the weight.

12. *Rule.*—Multiply the square of the depth by 4 times the breadth, and by S, and divide the product by the length for the breaking weight.

The weight, breadth, and depth being given, to find the length.

13. *Rule.* — Multiply 4 times the breadth by the square of the depth, and by S, and the product divided by the weight is the length.

The weight, length, and depth being given, to find the breadth.

14. *Rule.*—Multiply the length by the weight, and the product divided by 4 times the square of the depth multiplied by S, is the breadth.

The weight, length, and breadth being given, to find the depth.

15. *Rule.*—Multiply the length by the weight, and divide the product by 4 times the breadth multiplied by S.

When the section of the beam is square, and the weight and length are given, to find the side of the square.

16. *Rule.*—Multiply the length by the weight, and divide the product by 4 times S: the cube root of the quotient is the breadth or the depth.

3d. When the beam is *fixed* at both ends and loaded in the middle.

The breadth, depth, and length being given, to find the weight.

17. *Rule.*—Multiply 6 times the breadth by the square of the depth, and by S, and divide the product by the length for the weight.

It is not necessary to repeat all the transpositions of the equation.

4th. When the beam is *fixed* at both ends and loaded at an intermediate point.

18. *Rule.*—Multiply 3 times the length by the breadth, and by the square of the depth, and by S; and divide the product by twice the rectangle formed by the segments into which the weight divides the beam.

For example, if the beam is 20 feet long and the weight is placed at 5 feet from one end, then the segments are respectively 5 feet and 15 feet, or, in inches, 60 and 180; and the rectangle is $60 \times 180 = 10800$; and twice this amount, or 21600, is the divisor.

Suppose the beam of Riga fir, fixed at both ends, and its section 8×6 inches, and the weight placed at 5 feet from one end, required its breaking weight: then, three times the length $= 720$, multiplied by the product of the breadth into the square of the depth, and by the tabular value of S $= 306339840$; which divided by 21600, as above, gives 14,182 lbs. as the breaking weight.

5th. When the beam is supported at both ends, but not fixed, and when the load is in the middle.

To find the weight, when the length, breadth, and depth are given.

19. *Rule.* — Multiply 4 times the breadth by the square of the depth and by S, and divide the product by the length: the product is the breaking weight.

6th. When the weight is uniformly diffused.

20. *Rule.*—Multiply twice the breadth by the square

of the depth and by S, and divide the product by the length: the quotient is the breaking weight.

Note.—The beam bears twice as much when the load is uniformly diffused, as when it is applied in the middle of its length.

7th. When the load is at an intermediate point.

21. *Rule.*—Multiply the length by the breadth, by the square of the depth, and by S, and divide the product by the rectangle of the segment, that is, by the product of the shorter and longer divisions multiplied together.

IV. *Rules for the Dimensions of Beams to resist a Transverse Strain with a deflection of not more than* $\frac{1}{40}$*th of* 1 *inch per foot.*

The following are Mr. Tredgold's formulæ:—

8th. When the beam is supported at both ends and loaded in the middle.

When the weight, and the length and breadth are given, to find the depth.

22. *Rule.*—Multiply the square of the length in feet by the weight to be supported in lbs., and the product by the tabular value of a (Table VIII., column 10): divide the product by the breadth in inches, and the cube root of the quotient is the depth in inches.

When the weight, and the length and depth are given, to find the breadth.

23. *Rule.*—Multiply the square of the length in feet by the weight in lbs., and the product by the tabular value of a: divide by the cube of the depth in inches, and the quotient will be the breadth in inches.

When the weight and length are given, and the ratio of the breadth to the depth is to be as 0·6 *to* 1.

24. *Rule.*—Multiply the weight in lbs. by the tabular number a: divide the product by 0·6, and extract the square root: multiply the root by the length in feet, and extract the square root of the product, which will be the depth in inches.

To find the breadth,—multiply the depth by 0·6.

The following are the rules given by Mr. Barlow, for cases in which the amount of deflection is given.

9th. When the beam is fixed at one end, and loaded at the other, the weight in lbs., length in feet, and breadth and deflection in inches, being given, to find the depth.

25. *Rule.*—Divide the weight in lbs. by the tabular value of E (Table VII.; and column 13, Table VIII.) multiplied by the breadth and by the deflection; and the cube root of the quotient, multiplied by the length, will be the depth required.

10th. When the load is uniformly distributed.

26. *Rule.*—Take $\frac{3}{8}$ths of the actual weight, or, which is the same, multiply the weight by ·375, and then proceed as above.

11th. When the beam is supported at both ends, and loaded in the middle.

Given the weight in lbs., the length in feet, and the deflection in inches, to find the other dimensions.

27. *Rule.*—Multiply the weight by the cube of the length: divide the product by 16 times E, multiplied by the deflection, and the quotient is the breadth multiplied by the cube of the depth.

When the beam is intended to be square, the fourth root of the above quotient is the depth or breadth.

When it is a cylinder, multiply the quotient by 1·7, and the fourth root of the product is the diameter.

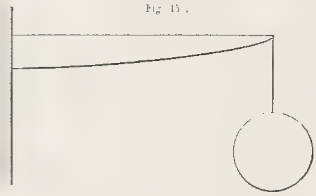
12th. When the load is uniformly distributed.

29. *Rule.*—Multiply the weight by ·625, and by the cube of the length, and divide the product by 16 times E, multiplied by the deflection: the quotient is the breadth multiplied by the cube of the depth.

If the reader has considered attentively the formulæ, he will have been led to the conclusion that in a parallel-sided beam exposed to transverse strain, much of the material does not aid in resisting the force of the weight; that, in point of fact, there must be some other form than that of the parallelopipedon, which shall give the greatest results with the least quantity of timber. This, which is called the *form of equal strength*, has been thoroughly investigated, and we shall here present the results.

In a beam fixed at one end, and loaded at the other, the form of equal strength is produced when the under

Fig. 451.



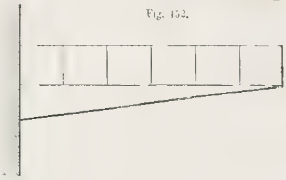
side is made a parabola, and the breadth uniform (Fig. 451).

When the depth is uniform, the figure of the beam is of a wedge form.

When the breadth and depth both vary, the form is a cubic parabola.

In a beam fixed at one end, and having its load uni-

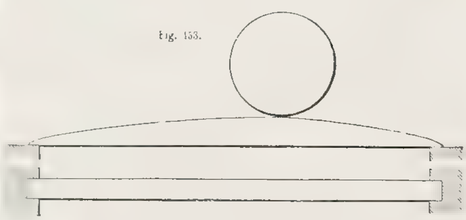
Fig. 452.



formly distributed, the form of equal strength is a triangle (Fig. 452).

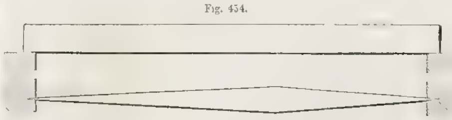
When a beam is supported at both ends, and loaded at

Fig. 453.



the middle or any intermediate point, and the breadth is the same throughout, its upper side should be composed of

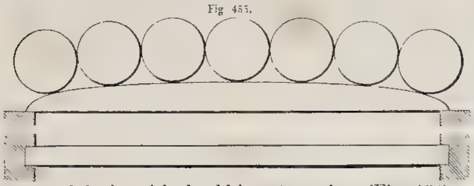
Fig. 454.



two parabolas whose vertices are at the points of support, and its lower side should be a straight line (Fig. 453).

When the depth is constant, the horizontal section or

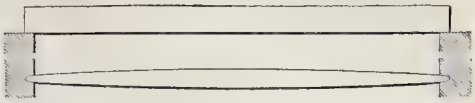
Fig 455.



outline of the breadth should be a trapezium (Fig. 454).

When it is loaded uniformly over its length, the upper side should be elliptical (Fig. 455).

Fig. 456.



When it is uniformly loaded, and the depth constant, the outline of the breadth should be two parabolas (Fig. 456).

TABLE VIII.—*Table of the Properties of Timber.*

	1.	2.	3.	4.	5.	6.	7.	8.	9.	Tredgold's Formulæ.		Barlow's Formulæ.	
										10.	11.	12.	13.
	Specific Gravity, Water being 1·0.	Weight of a foot, Dry, in lbs.	Weight of a Bar, 1 foot long, 1 inch sq., in lbs.	Absolute Tenacity of a sq. inch. Average, in lbs.	Tenacity of a sq. inch without injury, in lbs.	Modulus of Elasticity, in lbs.	Modulus of Elasticity, in feet.	Crushing force per sq. inch, in lbs.	Constants for Posts, and value of *e*.	Value of *a*	Value of C.	Value of S.	Value of E.
Acacia,	·710	44·37	·30	18,290	...	1,152,000	373,900	...	...	...	·621	·1867	...
Alder,	·800	50·	·347	14,186	...	...	...	6,895	...	...	...	...	...
Apple tree,	·793	49·56	·344	19,500	...	...	...	...	...	...	...	...	...
	·690	43·12	...	...	...	...	...	...					
Ash,	·845	53·81	...	17,207	3,540	1,644,800	4,970,000	8,683	·00168	·0105	·677	·2036	·244
	·760	47·5	·33	...	...	1,640,000	...	9,363					
Bay tree,	·822	51·37	·35	12,396	...	...	...	7,158	...	...	...	...	...
Beech,	·690	43·	...	...	...	...	...	7,733	...	...	...	...	...
	to ·854	53·37	·315	14,720	2,360	1,353,600	4,600,000	9,363	·00195	·0127	·552	·1556	·195
Birch,	·792	49·5	·34	15,000	...	...	5,406,000	6,402	...	·0141	·643	·1881	·240
„ American,	·648	40·5	·28	11,663	...	1,257,600	3,388,000	11,663	...	...	·605	·1834	·256
Box,	·960	60·	·41	19,891	...	...	...	...	...	...	...	...	...
Bullet tree,	1·029	64·31	·446	...	...	2,601,600	5,878,000	...	...	...	·882	·2646	...
Cane,	·400	25·	·174	6,300	...	...	...	...	...	..	...	...	...
Cedar, new,	·909	...	...	10,293	...	...	...	5,674	...	...	...	...	...
„ „ seasoned,	·753	47·06	·32	...	...	...	...	4,912	...	...	...	...	...
Chestnut,	·657	41·06	·285	11,900	...	...	...	...	...	·0187	...	...	...
Crab tree,	·765	47·81	·33	...	...	...	...	7,148	...	...	...	...	...
								6,499	...	...	...	...	...
Deal, Christiana,	·698	43·62	·30	12,400	...	1,672,000	5,378,000	6,586	...	·0095	·521	·1562	·230-·115
„ Memel,	·590	36·87	·25	...	...	1,536,200	6,268,000	...	...	·0089	·577	·1731	·190
„ Norway spruce,	·340	21·25	·147	17,600	...	...	...	7,293	·00142	...	...	...	...
„ English spruce,	·470	29·37	·20	7,000	...	...	...	...	...	·0124	...	...	...
Elder,	·695	43·43	·30	10,230	...	...	...	9,973	...	...	...	...	...
								8,467	...	...	...	...	...
Elm,	·544	34·	·236	...	3,240	1,340,000	5,680,000	...	·00184	·017	·372	·1115	·101
	·588	36·75	...	13,489	...	699,840	...	10,331					
Fir, Riga,	·753	47·06	·32	11,549	...	1,328,800	4,080,000	5,748	·00152	·00115	·369	·1108	·167
				12,776	...	869,600	...	6,819					
„ Red,	...	...	...	...	...	...	...	...	...	...	...	...	...
„ Mar,	·693	43·31	·30	12,000	...	...	2,797,000	...	...	·0233	·380	·1144	·94
Hawthorn,	·91	38·12	·26	10,500	...	...	...	...	...	...	...	...	...
Hazel,	·86	53·75	·36	18,000	...	...	...	...	...	...	...	...	...
Holly,	·76	47·5	·32	16,000	...	...	...	...	...	...	...	...	...
Hornbeam,	·76	47·5	·32	20,240	...	...	...	7,289	...	...	...	...	...
Laburnum,	·92	57·50	·40	10,500	...	...	...	...	...	...	...	...	...
Lance,	1·022	63·87	·44	23,400	...	...	...	...	...	...	...	...	...
Larch,	·522	32·62	...	10,220	...	10,740,000	4,415,000	5,568	·0019	·0128	·284	·853	·120
	·560	35·	·243	8,900	2,065	1,052,800	...	...					
Lignum-vitæ,	1·22	76·25	·53	11,800	...	...	...	...	...	...	...	...	...
Lime tree,	·760	47·50	·32	23,500	...	...	...	...	...	·0152	...	...	...
Mahogany, Spanish,	·800	50·	·34	16,500	...	...	...	8,198	·00205	·0137	...	...	...
„ Honduras,	·560	35·	·243	18,950	3,800	1,596,300	6,570,000	...	·00161	·0109	...	...	...
Maple,	·793	49·56	...	10,584	...	...	...	...	...	·0197	...	...	...
								4,684					
Oak, English,	·830	52·	·36	...	3,960	1,700,000	4,730,000	9,509	·0015	·0124	·553	·1658	·210
	·934	58·37	...	13,316	...	1,451,220	...	10,058					
„ Canadian,	·872	54·50	·378	10,253	...	2,148,800	5,674,000	4,231	...	·009	·588	·1766	·310
								9,509					
„ Danzic,	·756	47·24	·327	12,780	...	1,191,200	3,607,000	7,731	...	·0087	·560	·1457	·149
„ Adriatic,	·993	62·06	·43	...	...	974,400	2,257,000	...	...	...	·526	·1383	...
„ African,	·972	60·75	·42	...	...	2,282,300	5,583,000	...	...	...	...	...	...
Pear tree,	·661	41·31	·283	9,861	...	...	...	7,518	...	·0215	...	...	...
Pine, Pitch,	·660	41·25	·283	7,818	...	1,225,600	4,364,000	6,790	...	·0166	·544	·1632	·177
								5,445					
„ Red,	·607	41·06	·26	10,000	...	1,840,000	6,423,000	5,375	...	·0109	·447	·1341	·272
								7,518					
„ American yellow,	·461	28·81	·20	...	3,900	1,600,000	8,700,000	5,445	...	·0112	...	...	...
Plane tree,	·640	40·	·28	11,700	...	...	...	...	...	·0128	...	...	...
								10,493	...	...	...	...	...
Plum tree,	·786	49·06	·338	11,351	...	...	...	9,367	...	...	...	...	...
								3,657, wet.	...	...	...	...	...
Poplar,	·383	23·93	·164	6,016	...	...	...	3,107	...	·0224	...	...	...
								5,124					
Sycamore,	·69	43·1	·296	13,000	...	...	...	...	...	·0168	...	...	...
Teak,	·657	41·06	·282	12,460	...	2,414,400	7,417,000	12,101	·00118	·0076	·820	·2462	·349
Walnut,	·671	41·93	·288	8,465	...	...	...	7,227	...	·020	...	...	...
Willow,	·390	24·37	·167	14,000	...	...	...	6,128	...	·031	...	...	...
Yew, Spanish,	·807	50·43	·347	8,000	..	...	...	...	...	...	...	...	...

PART FIFTH.

PRACTICAL CARPENTRY.

ROOFS.

Roofs may be variously classed, according to their forms, and the combinations of their surfaces. The simplest are those which have either plane surfaces, or cylindric surfaces having their generatrix horizontal.

The slope given to a roof is for the purpose of throwing off rapidly the water of rain or of snow, in order that the materials of the roof may be quickly dry. Many authors have occupied themselves in investigating the different slopes which should be given to roofs, according to the climate and the materials used as covering.

The flat roofs or terraces of the East, and the high-pitched roofs of the countries of the North, the extremes of the scale, might lead to the supposition that climate alone had determined the proper slope to be adopted. Accordingly, M. Quatremère de Quincy proposed to regulate the slopes of roofs rigorously in accordance with the latitude; thus, commencing at zero at the equator, he elevates the roof 3° for each geographical climate* when the covering materials is pan tiles, and adds 3° more when the covering is of Roman tiles, 6° when it is of slates, and 8° when formed of plain tiles. This proposition of M. de Quincy has been converted into a simple formula by M. Belmas, thus expressed:—Make the slope of the roof equal to the excess of the latitude of the place where it is constructed over that of the tropics. The latitude of the tropics being 23° 28′, the rule would give, for a roof in latitude 25°, a slope of only 1° 32′. But on so small an inclination as this, the necessary overlap of the tiles or slates would cause them to slope the reverse way, and the water would consequently penetrate under them.

But climate does not appear in practice to be the regulator of the slopes of roofs; for in the same place are found roofs of various slopes, and neither the original proposition of M. de Quincy, nor the form of it proposed by M. Belmas, are verified by experience. Indeed, the rule would seem to be based on a too limited series of observation, and gives slopes too low for moderate climates, and too high for those in warm regions where terraces are invariably used.

The following table shows the slopes actually in use in certain places, and the slopes according to M. de Quincy's rule:—

Places.	Climates.	Slopes according to M. de Quincy's Rule.	Covering used.	Actual Slopes.
St. Petersburg,...	14°	10 24′	Iron.	18° to 20°
Copenhagen, ...	11	32 48	Slates.	45 to 60
Hamburg, ...	10	37 48	Plain tiles.	45 to 60
Brussels, ...	9	34 30	„	60°
Paris, ...	9	32 36	„	45 to 60
		30 36	Slates.	33 to 45
		24 36	Pan tiles.	18 to 25
Colmar, ...	9	32 0	Plain tiles.	60°

The empiric rule, then, giving results so widely different from what experience has taught, is not to be relied on, and some other data on which to base our practice must be found. M. Rondelet, indeed, regards the slope to be given to roofs as altogether arbitrary, and dependent on taste alone, with such restrictions only as the more or less perfect nature of the materials impose.

It is, indeed, extremely probable that the slopes of roofs were regulated originally according to the materials used as a covering. The inclination is generally uniform in all places where the same kind of materials is used. A thatch of leaves, bark, straw, or reeds, probably the first kind of covering employed, required a very steep slope that the water might be speedily thrown off. And when in course of time the more perfect covering of tiles and slates came to be applied, the habit of imitation would for a while prevent any change in the accustomed slope. However this may be, it is evident that the variety of slopes in the same localities shows that no precise rule can now be drawn from existing examples. In roofs covered with slates, the height, or pitch, of the roof is made from one-fourth of the width of the span to the whole width of the span, that is, the slope varies from an angle of 26° 30′ with the horizon to 60°; and writers assuming 26° 30′ as the smallest angle for common slates, have given the following rates of inclination for other materials:—

Kind of Covering.	Inclination to the Horizon.	Height of Roof in parts of the Span.	Weight on a Square of Roofing.
Copper, ...	3° 50′	$\frac{1}{24}$	100
Lead, ...	3° 50′	$\frac{1}{24}$	700
Large slates, ...	22 0	$\frac{1}{5}$	1120
Common slates,...	26 30	$\frac{1}{4}$	500 to 900
Stone slates,.......	29 41	$\frac{2}{7}$	2380
Plain tiles..........	29 41	$\frac{2}{7}$	1780
Pan tiles,..........	24 0	$\frac{2}{9}$	650
Thatch,............	45 0	$\frac{1}{2}$	...

Colonel Emy says, that the inclination of roofs covered with plain tiles varies in France within the limits of 40° and 60°. As the tiles are not nailed like slates, they are made to resist the wind by the pressure of their weight. The angle of 45°, he observes, is the best for roofs covered with slates or plain tiles, a slope that permits the use of the interior of the roof as garrets. When the slope is more gentle, the scantling of the roof timbers require to be increased; and when more steep, the increase of roof surface and augmentation of the

* The space comprised between the equator and each polar circle is divided into 24 zones or climates, the limits of which are determined by a difference of half an hour in the length of the day in the summer solstice. Thus, leaving the equator where the latitude is zero, and the length of the longest day 12 hours, the circles of separation are fixed as in the following table, where the Roman numerals are the climates, and the opposite corresponding numbers are the latitudes at which the climates finish, up to the 24th, which terminates at the polar circle, where the length of the longest day is 24 hours:—

I.	8° 25′	VII.	45° 29′	XIII.	59° 58′	XIX.	65° 24′
II.	16 25	VIII.	49 1	XIV.	61 18	XX.	65 47
III.	23 50	IX.	51 58	XV.	62 25	XXI.	66 6
IV.	30 20	X.	54 27	XVI.	63 22	XXII.	66 20
V.	36 28	XI.	56 37	XVII.	64 6	XXIII.	66 28
VI.	41 22	XII.	58 29	XVIII.	64 49	XXIV.	66 30

length of the timbers increases the cost, without a corresponding benefit, as the height gained cannot be usefully occupied internally, unless by making two stories of apartments in the roof, a practice which, in the present day, is very properly abandoned. The result of an extended consideration of the subject is given by Colonel Emy as follows:—

In roofs covered with tiles hung on laths, the slope should not be greater than that at which the materials would slide naturally. It should, therefore, not exceed an angle of 27° with the horizon. Its lowest limit should be such that the tiles should never have so small a slope by their overlap that the water would stagnate.

In roofs with metallic coverings, the slope requires to be only sufficient to cause the flow of the water; and, therefore, need not exceed $\frac{1}{40}$th of the span.

The following table is extracted from his work:—

Kinds of Roofs and of Coverings.	Proportion of the Span.	Inclination to the Horizon.
Antique temples,............	$\frac{1}{12}$ and $\frac{1}{8}$	9° 28′ to 14° 2′
Hollow tiles, Roman tiles, and metal,................	$\frac{1}{6}$ and $\frac{1}{4}$	18 26 to 26 33
Slates, lowest inclination,..	$\frac{1}{3}$	33° 46′
Thatch, common slates, plain tiles, &c.,......... ..	$\frac{3}{8}$	36 52
	2	45 0
	1	60 0

On the subject of the pitch of roofs, Professor Robison remarks as follows:—" A high-pitched roof will undoubtedly shoot off the rains and snows better than one of a lower pitch. The wind will not so easily blow the dropping rain in between the slates, nor will it have so much power to strip them off. A high-pitched roof will exert a smaller thrust on the walls, both because its strain is less horizontal, and because it will admit of higher covering. But it is more expensive, because there is more of it. It requires a greater size of timbers to make it equally strong, and it exposes a greater surface to the wind. There have been great changes in the pitch of roofs: our forefathers made them very high, and we make them very low. It does not, however, appear that this change has been altogether the effect of principle. In the simple, unadorned habitations of private persons, everything comes to be adjusted by our experiences, which have resulted from too low-pitched roofs; and their pitch will always be such as suits the climate and covering. Our architects, however, go to work on different principles. Their professed aim is to make a beautiful object. The sources of the pleasure arising from what we call taste are so various, so complicated, and even so whimsical, that it is almost in vain to look for principle in the rules adopted by our professed architects."—" The Greeks, after making a roof a chief feature of a house, went no further, and contented themselves with giving it a slope suited to their climate. This we have followed, because in the milder parts of Europe we have no cogent reasons for deviating from it. And if any architect should deviate greatly in a building where the outline is exhibited as beautiful, we should be disgusted; but the disgust, though felt by almost every spectator, has its origin in nothing but habit. In the professed architect or man of education, the disgust arises from pedantry; for there is not such a close connection between the form and uses of a roof as shall give precise determinations; and the mere form is a matter of indifference. We should not, therefore, reprobate the high-pitched roofs of our ancestors, particularly on the Continent. It is there where we see them in all the extremity of the fashion; and the taste is by no means exploded as it is with us."

The conclusion to be arrived at is then, as expressed by Professor Robison, " that there is not such a close connection between the form and uses of a roof as shall give precise determinations, and the mere form is a matter of indifference."

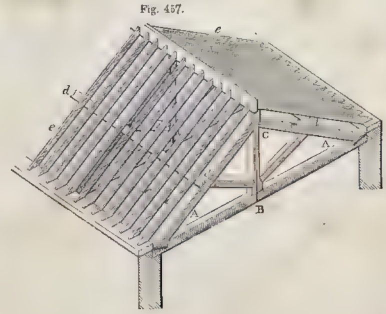
EXAMPLES OF THE CONSTRUCTION OF ROOFS.

Roofs of two slopes in narrow buildings are composed of rafters alone, with a cross piece, forming each pair of opposite rafters into what is termed a *couple*. The rafters without the cross piece, or *tie-beam*, would tend to thrust out the walls on which they rest; and this cross piece is intended therefore to act as a tie to counteract this thrust. Its position is consequently of importance; and from a false economy, or from ignorance of its function, it is generally, in buildings of an inferior class, placed so high as to be of little use in counteracting the thrust.

This kind of roof, the couple-roof, is only practicable in buildings of very moderate width. In wide buildings, the rafters would bend by their own weight, unless made of a preposterous size or supported in some manner. When the width of the building, therefore, exceeds these moderate limits, the rafters are kept from bending by a piece of timber parallel to the tie-beam, and called a *collar-beam*. But it will be obvious that couple-roofs so formed, independently of consuming a great quantity of timber, can only, after all, be used for small spans; and hence it is necessary to have recourse to the framed roof. In framed roofs, the rafters are sustained by pieces of timber, which lie under them horizontally, and divide their length into spaces within the limit of their flexure under the weight of the covering. These horizontal pieces are called *purlins*, and are sustained by trussed frames of carpentry, distributed transversely at equal distances in the length of the building, the distances being calculated with relation to the strength of the *purlins*.

Fig. 457 illustrates this kind of roofs, in which A A, B C is the trussed frame of carpentry, called a *principal*, *d d*

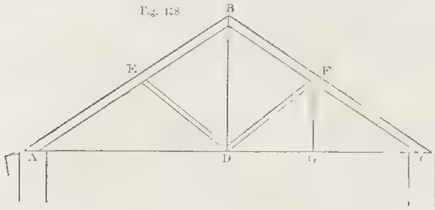
Fig. 457.



are the purlins, and *e e* the rafters. It will be useful here to consider the principles of trussing.

Let A B, C B (Fig. 458) be two rafters, placed on walls at A and C, and meeting in a ridge B. Even by their own weight, and much more when loaded, these rafters would have a tendency to spread outwards at A and C, and to

Fig. 458.



sink at B. If this tendency be restrained by a tie established betwixt A and C, and if A B, B C be perfectly rigid, and the tie A C incapable of extension, B will become a fixed point. This, then, is the ordinary couple-roof, in which the tie A C is a third piece of timber; and which may be used for spans of limited extent; but when the span is so great that the tie A C tends to bend downwards or sag, by reason of its length, then the conditions of stability obviously become impaired. Now, if from the point B a string or tie be let down and attached to the middle D, of A C, it will evidently be impossible for A C to bend downwards so long as A B, B C remain of the same length: D, therefore, like B, will become a fixed point, if the tie B D be incapable of extension. But the span may be increased, or the size of the rafters A B, C B be diminished, until the latter also have a tendency to sag; and to prevent this, pieces D E, D F are introduced, extending from the fixed point D to the middle of each rafter, and establishing F and E as fixed points also, so long as D E, D F remain unaltered in length. Adopting the ordinary meaning of the verb "to truss," as expressing to tie up (and there seems to be no reason why we should seek further for the etymology), we truss or tie up the point D, and the frame A B C is a trussed frame. In like manner, F being established as a fixed point, G is trussed to it. In every trussed frame there must obviously be one series of the component parts in a state of compression, and the other in a state of extension. The functions of the former can only be filled by pieces which are rigid, while the place of the latter may be supplied by strings. In the diagram, the pieces A B, C B are compressed, and A C, D B are extended; yet in general the tie D B is called a *king-post*, a term which conveys an altogether erroneous idea of its duties. Thus we see how the two principal rafters, by their being incapable of compression, and the tie-beam by its being incapable of extension, serve, through the means of the king-post, to establish a fixed point in the centre of the void spanned by the roof, which again becomes the *point d'appui* of the struts, which at the same time prevent the rafters from bending, and serve in the establishing of other fixed points; and the combination of these pieces is called a king-post roof.

It is sometimes, however, inconvenient to have the centre of the space occupied by the king-post, especially where it is necessary to have apartments in the roof. In such a case recourse is had to a different manner of trussing. Two suspending posts are used, and a fourth element is introduced, namely, the *straining beam a b* (Fig. 459), extending between the posts. The principle of trussing is the same. The rafters are compressed, the straining beam is compressed, and the tie-beam and posts, the latter now called *queen posts*, are in a state of tension.

In some roofs, for the sake of effect, the tie-beam does not stretch across between the feet of the principals, but is interrupted. In point of fact, although occupying the

Fig. 459.

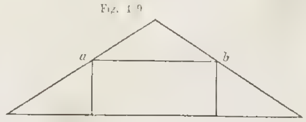
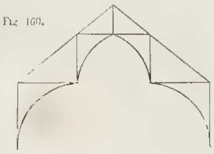


Fig. 460.



place of, it does not fill the office of a tie-beam, but acts merely as a bracket attached to the wall (Fig. 460). It is then called a *hammer-beam*.

It is a general rule that wood should be used as struts and iron as ties; and in many modern trusses this rule has been admirably exemplified by the combination of both materials in the frames.

There is another class of principals in which tie-beams are not used. Such are the curved principals of De Lorme and Emy. In the system of Philibert de Lorme, arcs formed of small scantlings of timber are substituted for the framed principals; and in that of Colonel Emy, laminated arcs are used.

The principals of roofs may therefore, in respect of their construction, be divided broadly into two classes—First, Those with tie-beams; and, Second, Those without tie-beams.

The first class, those with tie-beams, may be further classified as king-post roofs and queen-post roofs.

The second class may be arranged as follows:—

1st. Hammer-beam roofs.

2d. Curved principal roofs.

And sometimes the classes are combined.

Examples of the varieties of all these will be found in the plates; and we shall now proceed to describe these examples. Our explanations shall, however, be limited to such parts of the construction for which an explanation is indispensable, and which cannot be readily understood by an inspection of the engravings.

As preliminary to the explanation of the examples, it may however be well here to give Mr. Tredgold's rules for proportioning the strength of the various pieces composing the roof; but while we do so, it is necessary to caution the student that these rules are empirical and too general to be relied on, except in simple cases. It is far better, however, although it is commonly attended with more labour, to trust to the formulæ given in the article on the strength of timber, applying the rules specially to each case.

In estimating the pressure on a roof, for the purpose of apportioning the proper scantlings of timber to be used, not only the weight of the timber and the slates, or other covering, must be taken, but also the weight of snow which in severe climates may be on its surface, and also the force of the wind, which we may calculate at 40 lbs. per superficial foot.

The weight of the covering materials, and the slope of roof, which is usually given, are contained in the following table:—

Material.	Inclination.	Weight on a Square Foot.
Tin	Rise 1 inch to a foot.	$\frac{5}{8}$ to $1\frac{1}{4}$ lbs.
Copper	" 1 " "	1 " $1\frac{1}{2}$ "
Lead	" 2 " "	4 " 7 "
Zinc	" 3 " "	$1\frac{1}{4}$ " 2 "
Short pine shingles	" 5 " "	$1\frac{1}{2}$ " $2\frac{1}{2}$ "
Long cypress shingles	" 6 " "	4 " 5 "
Slate	" 6 " "	5 " 9 "

With the aid of this table, and taking into account the pressure of the wind and the weight of snow, the strength of the different parts may be calculated, as we have said, by the rules given under the head—"Strength of Materials;" but the following empirical rules, deduced by Mr. Tredgold from these, and from experience, will be found of easy application, and useful for simple cases. Mr. Tredgold assumes $66\frac{1}{2}$ lbs. as the weight on each square foot.

It is customary to make the rafters, tie-beams, posts, and struts all of the same thickness.

Mr. Tredgold's Rules.

IN A KING-POST ROOF OF PINE TIMBER.

To find the dimensions of the principal rafters.

Rule.—Multiply the square of the length in feet by the span in feet, and divide the product by the cube of the thickness in inches; then multiply the quotient by 0·96 to obtain the depth in inches.

Mr. Tredgold gives also the following rule for the rafters, as more general and reliable:—

Multiply the square of the span in feet by the distance between the principals in feet, and divide the product by 60 times the rise in feet: the quotient will be the area of the section of the rafter in inches.

If the rise is one-fourth of the span, multiply the span by the distance between the principals, and divide by 15 for the area of section.

When the distance between the principals is 10 feet, the area of section is two-thirds of the span.

To find the dimensions of the tie-beam, when it has to support a ceiling only.

Rule.—Divide the length of the longest unsupported part by the cube root of the breadth, and the quotient multiplied by 1·47 will give the depth in inches.

To find the dimensions of the king-post.

Rule.—Multiply the length of the post in feet by the span in feet: multiply the product by 0·12, which will give the area of the section of the post in inches. Divide this by the breadth for the thickness, or by the thickness for the breadth.

To find the dimensions of struts.

Rule.—Multiply the square root of the length supported in feet by the length of the strut in feet, and the square root of the product multiplied by 0·8 will give the depth, which multiplied by 0·6 will give the thickness.

IN A QUEEN-POST ROOF.

To find the dimensions of the principal rafters.

Rule.—Multiply the square of the length in feet by the span in feet, and divide the product by the cube of the thickness in inches: the quotient multiplied by 0·155 will give the depth.

To find the dimensions of the tie-beam.

Rule.—Divide the length of the longest unsupported part by the cube root of the breadth, and the quotient multiplied by 1·47 will give the depth.

To find the dimensions of the queen-posts.

Rule.—Multiply the length in feet of the post by the length in feet of that part of the tie-beam it supports: the product multiplied by 0·27 will give the area of the post in inches; and the breadth and thickness can be found as in the king-post.

The dimensions of the struts are found as before.

To find the dimensions of a straining-beam.

Rule.—Multiply the square root of the span in feet by the length of the straining-beam in feet, and extract the square root of the product: multiply the result by 0·9, which will give the depth in inches. The beam, to have the greatest strength, should have its depth to its breadth in the ratio of 10 to 7; therefore, to find the breadth, multiply the depth by 0·7.

To find the dimensions of purlins.

Rule.—Multiply the cube of the length of the purlin in feet by the distance the purlins are apart in feet, and the fourth root of the product will give the depth in inches, and the depth multiplied by 0·6 will give the thickness.

To find the dimensions of the common rafters, when they are placed 12 inches apart.

Rule.—Divide the length of bearing in feet by the cube root of the breadth in inches, and the quotient multiplied by 0·72 will give the depth in inches.

We shall, by way of practice, test the scantlings of some of the examples of executed roofs by these rules, which is preferable to working out supposititious examples in this place.

It may be well here, also, before describing the examples, to note some practical memoranda of construction which cannot be too closely kept in mind in designing roofs.

Beams acting as struts should not be cut into or mortised on one side, so as to cause lateral yielding.

Purlins should never be framed into the principal rafters, but should be notched. When notched, they will carry nearly twice as much as when framed.

Purlins should be in as long pieces as possible.

Rafters laid horizontally are very good in construction, and cost less than purlins and common rafters.

The ends of tie-beams should be kept with a free space round them, to prevent decay. It is said that girders of oak in the Chateau Roque d'Ondres, and girders of fir in the ancient Benedictine monastery at Bayonne, which had their ends in the wall wrapped round with plates of cork, were found sound, while those not so protected were rotten and worm-eaten.

It is an injudicious practice to give an excessive camber to the tie-beam: it should only be drawn up when deflected, as the parts come to their bearings.

The struts should always be immediately underneath that part of the rafter whereon the purlin lies.

The diagonal joints of struts should be left a little open at the inner part, to allow for the shrinkage of the heads and feet of the king and queen posts.

It should be specially observed that all cranks or bends in iron ties are avoided.

And, as an important final maxim—*Every construction should be a little stronger than strong enough.*

Description of the Plates.

Plate XXII.—*Fig.* 1 is the elevation of a king-post roof, designed by Mr. White, for a span of 30 feet.

By the rules given for calculating the scantling, it will be found to be as follows:—

A, Tie-beam, ...	13 × 5	inches.
B, Principal rafters, ...	8¼ × 5	„
C, Struts, .	4 × 2½	..
D, King-post, ...	7¼ × 5	..

Fig. 2 is the design for a king-post roof, for a span of 33 feet 6 inches.

The purlins here are shown framed into the principals, a mode of construction to be avoided, unless rendered absolutely necessary by particular circumstances.

The scantling, as determined by the rules, is as follows:—

Principal rafters, ...	10 × 5	inches.
Tie-beam, ...	11½ × 6	..
King-post, ...	7¾ × 6	„
Struts, ...	4 × 2½	„
Purlins, ...	10 × 6	..

The principals being 10 feet apart.

Fig. 3.—A compound roof for a span of 30 feet. It is composed of a curved rib C C, formed of two thicknesses of 2-inch plank bolted together. Its ends are let into the tie-beam; and it is also firmly braced to the tie-beam by the king-post and suspending pieces B B, which are each in two thicknesses, one on each side of the rib and tie-beam, and by the straps *a a*. A is the rafter; *d*, the gutter-bearer; *c* and *b*, the straps of the king-post. The second purlins, it will be observed, are carried by the upper end of the suspending pieces B B.

Full details of the straps and bolts of this and the succeeding examples will be found in Plates XXXVIII. and XXXIX., "Joints and Straps."

Fig. 4.—A queen-post roof, with an iron king-bolt, intended for a span of 32 feet.

A, Principal rafter, ...	11 × 5	inches.
B, Straining-piece, ...	11 × 5	..
C, Queen-post, ..	9 × 5	..
Struts, ...	5 × 4	„

c, King-bolt.

The common rafters are 8 × 3 inches, and project over the walls to form a projecting cornice: *a* is the short ceiling-joist of the cornice; *b*, an ornamental bracket.

Fig. 5.—A queen-post roof for a span of 60 feet. The scantlings are as follows:—

Principal rafters, ...	11 × 6	inches.
Tie-beam, .	12¼ × 6	..
Queen-post B, ...	8 × 6	.
Suspending post A,	3½ × 3	.
Struts (large), ...	4½ × 3½	„
„ (small), ...	3½ × 2½	„

Fig. 6.—Nos. 1, 2, 3, and 4 are the elevation and details of the queen-post roof of the railway workshops at Worcester. The principals are placed 15 feet apart, and the purlins are trussed. The details are as follows:—

Principal rafters, ...	8 × 8	inches.
Tie-beam, ..	12 × 8	..
Queen-post	8 × 6	
Struts	4½ × 4½	„
Straining-beam,	9 × 8	..
Common rafters, ...	4½ × 2	..
Purlins, in two flitches each (trussed with stirrup pieces and iron ties), ...	9 × 3	..

The tie-beams are carried on iron shoes.

No. 1 is the elevation of the roof. No. 2 is a section of one bay of the roof. No 3 shows the under side, and No. 4 the side of a purlin drawn to a larger scale.

Fig. 7.—Elevation of the principal of a platform roof for a span of 70 feet. The tie-beam in this example is scarfed at *a* and *b*, and the centre part of the roof has counter-braces *c c*. The longitudinal pieces *e e*, secured to the heads of the queen-posts, and the piece *d*, carry the platform joists A. The details of the scarfing and strengthening the tie-beam will be found described in the section on "Scarfing and Lengthening Beams," and illustrated in Plate XXXIX.

Plate XXIII.—*Fig.* 1 is a queen-post M-roof, for a span of 47 feet; or rather, having a king-bolt in the centre, it is a compound roof:—

A, Tie-beam, ...	13 × 6	inches.
B, Principal rafter, ...	11 × 6	..
C, Straining-beam, ...	11 × 6	..
D, Queen-post, ...	7 × 6	..
E, Strut, ...	7 × 6	..
F, Counter-brace, ...	6 × 6	..
G, Common rafter, ...	6 × 2½	..
a, Wall plate for common rafters, .	7 × 9	„
b b, Purlins, ...	11 × 6	„
e g, King-bolt, ...	2 inches diameter.	
d, Ridge-rafter, ...	12 × 2½	inches.
h, Gutter-bearer, ...	3 × 2½	„

In this roof, the purlins are shown framed into the principals, a practice which has already been censured.

Fig. 2.—A simple queen-post roof for a span of 40 feet:—

A, Tie-beam, ...	12 × 6	inches.
B, Principal rafter,	10 × 6	..
C, Straining beam, ...	9 × 6	..
D, Queen-post, . .	8 × 6	..
E, Strut, ...	6 × 6	..
F, Common rafter, ...	6 × 2½	„
a, Wall-plate,	9 × 6	..
b, Purlin, . .	12 × 9	..

c, Ridge-rafter; *d*, strap at foot of common rafter; *e*, ditto at foot of queen-post; *f*, ditto at head of ditto; *k*, straining-cill.

Fig. 3.—King-post roof for a span of 38 feet 9 inches:—

	As Executed	As Determined by the Rule
Tie-beam, ...	11 × 9 ins.	11½ × 6 ins.
King-post, ...	10 × 8 „	8 × 6 „
Suspending posts or queen-posts,	10 × 7 „	5 × 3 „
Principal rafters, ...	10 × 7 „	8 × 6 „
Principal struts, ...	6 × 6 „	6 × 3 „
Secondary struts, . ..	5 × 5 ..	3 × 2 „
Purlins, .. .	7 × 9 „	
Cleets at back of purlins, ...	8 × 6 „	
Ridge piece, ...	8 × 1½ „	

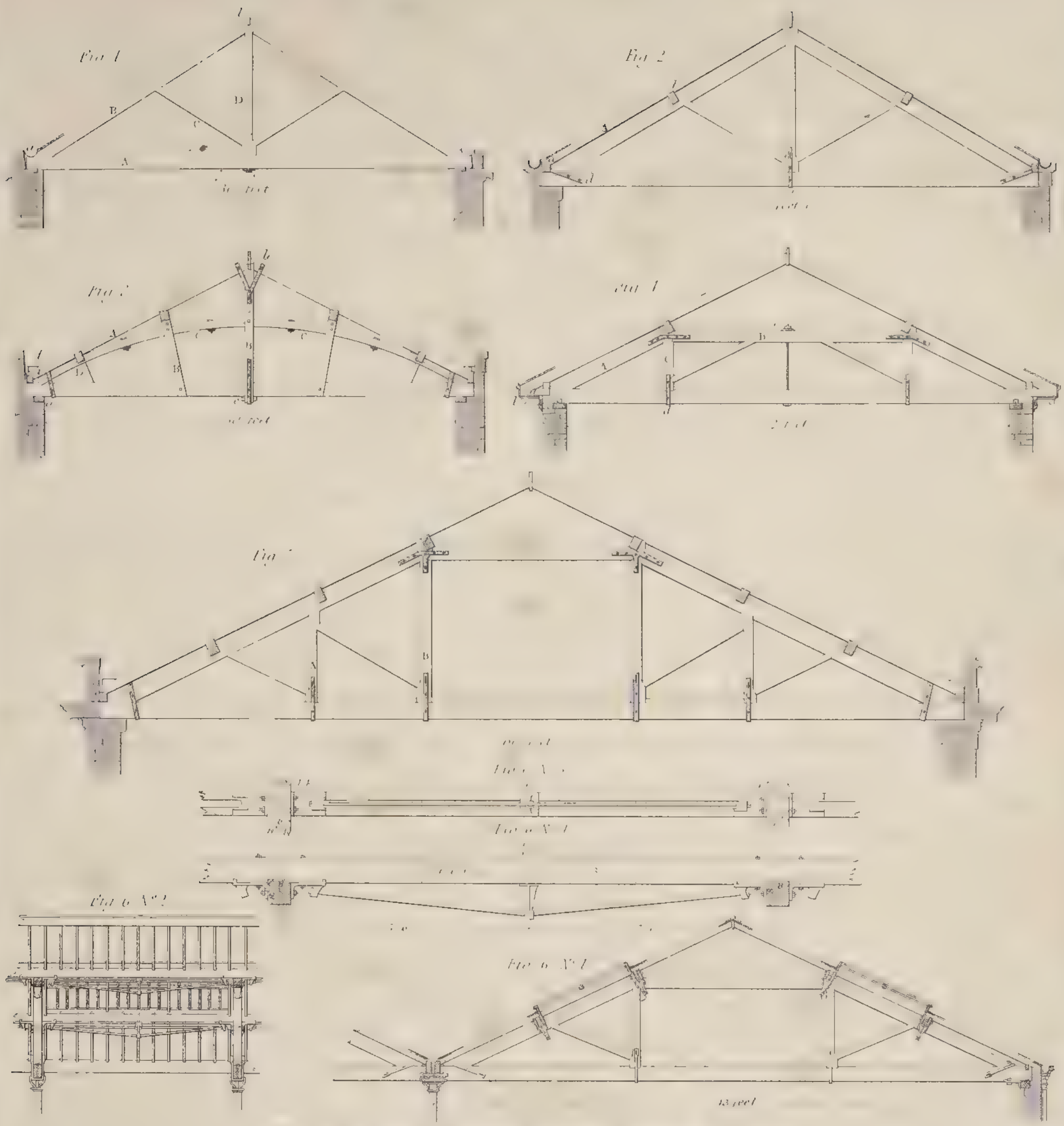
On comparing the scantlings of this roof as executed, with those derived from the application of Mr. Tredgold's formulæ, there will be found an excess of strength. The scantlings, in point of fact, are nearly as large as those of other examples, of much greater span, which we have given; and this roof, therefore, suffers much in comparison with the next example, where the scantlings, as executed, are, generally speaking, of smaller dimensions than those resulting from the application of the formulæ.

The tie-beam is strapped to the king and queen posts, and the principal rafters are secured by screwed bolts and nuts.

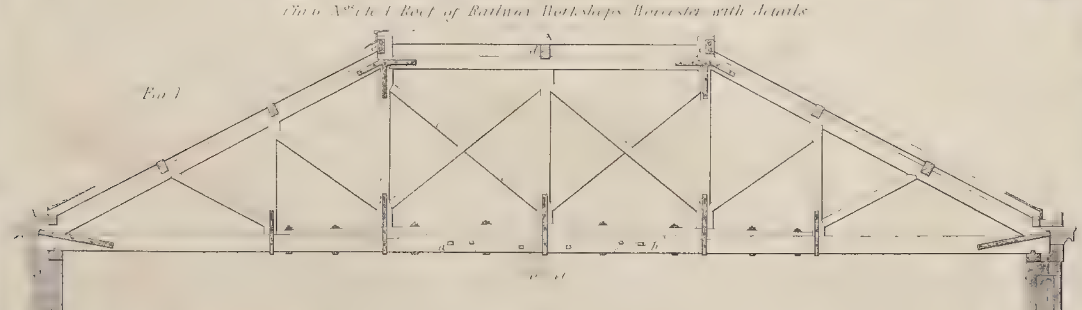
Fig. 4.—No. 1 is the elevation of one of the trusses of George Heriot's Schools, Edinburgh, designed by Alexander Black, Esq., architect, and executed under his superintendence.

The dimensions of the scantlings by the rules are here

ROOFS.



Figs 6 Nos 1 to 4 Roof of Railway Workshops Worcester with details



10 20 30 40 50 Feet

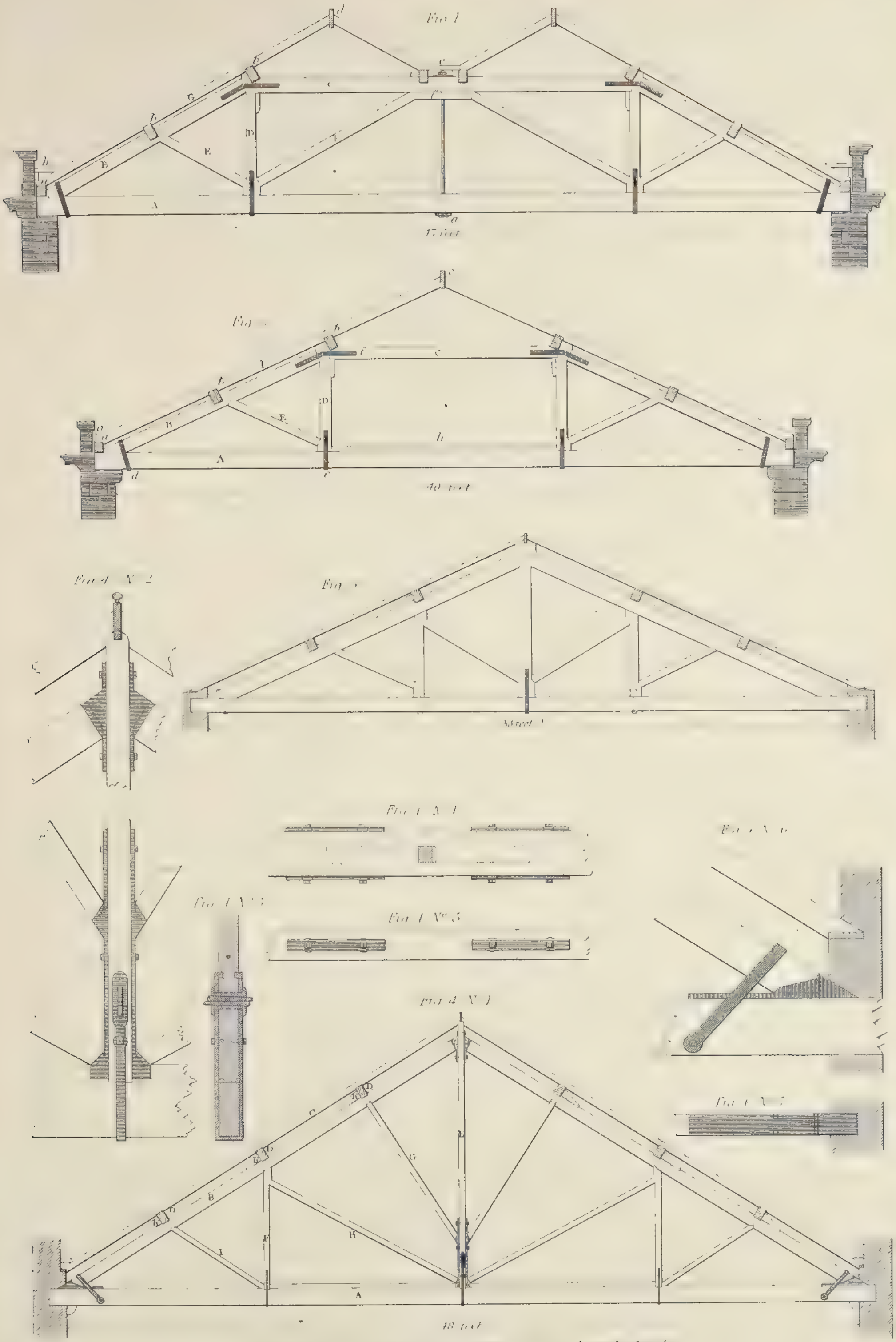
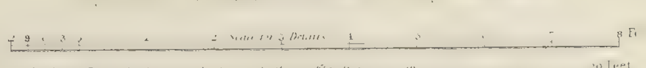


Fig. 4 Nos 1 to 6. Roof of Heriots school Edinburgh with details

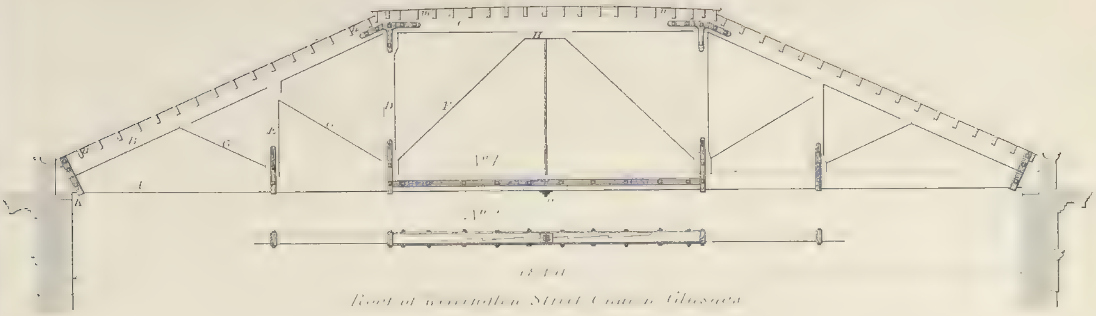


J White del

J. W. Lowry sc

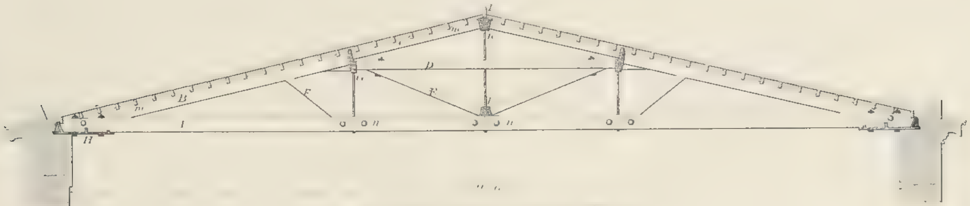
BLACKIE & SON GLASGOW EDINBURGH & LONDON

Fig. 1.



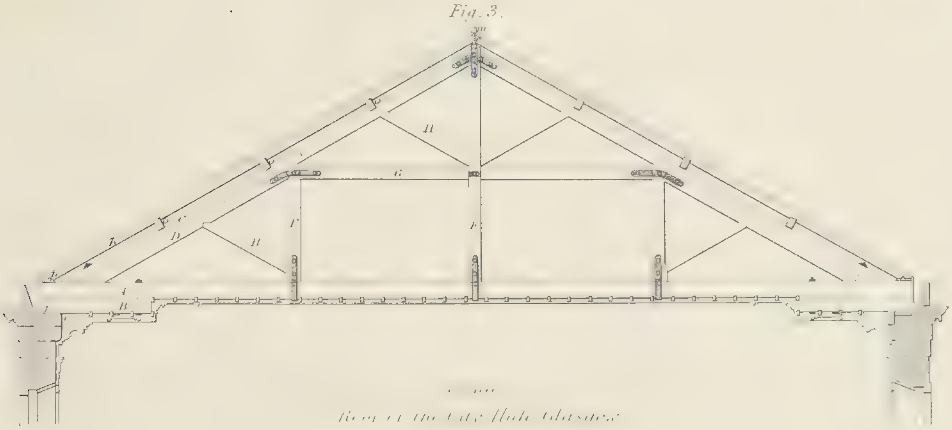
Roof of [illegible] Street Church Glasgow

Fig. 2.



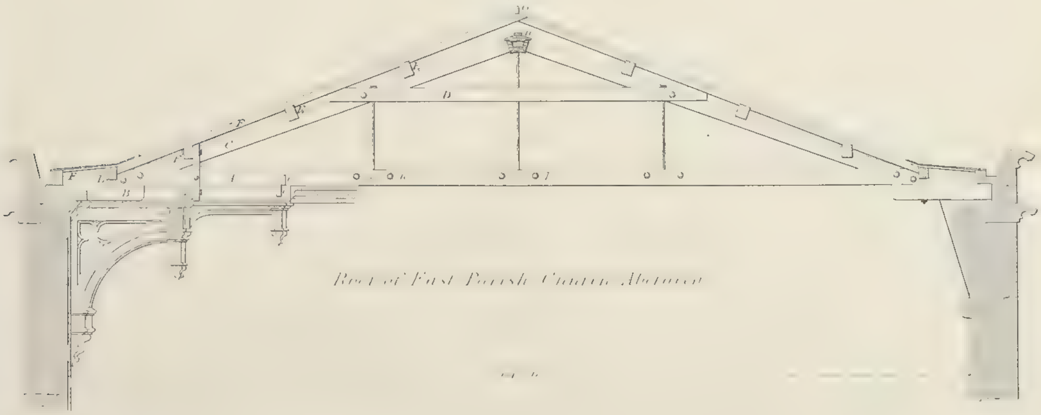
Roof of the Parish Church [illegible]

Fig. 3.



Roof of the City Hall Glasgow

Fig. 4.



Roof of East Parish Church [illegible]

J. White, del.

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W. A. Beever, Sc.

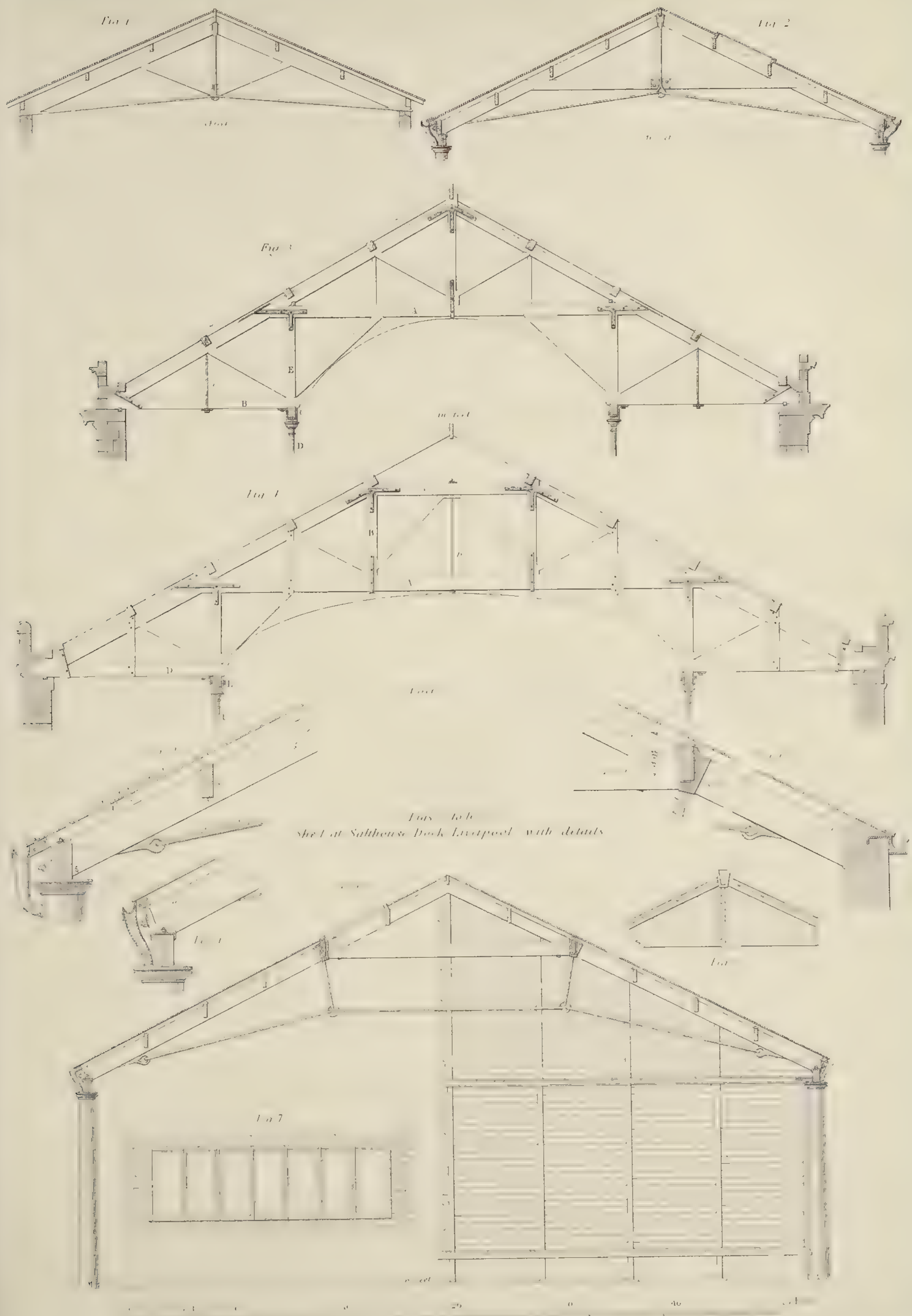


Fig. 1
Fig. 2
Fig. 3
Fig. 4
Figs. 5 to 6
Shed at Salthouse Dock Liverpool with details
Fig. 7

placed in juxtaposition with the dimensions of the scantlings as executed, as follows:—

	By the Rule.	As Executed.
A, Tie-beam, ...	$11\frac{3}{4} \times 4$ inches.	12×4 inches.
B, Principal rafters, ...	8×4 „	8×4 „
C, Common rafters, ...	...	$5 \times 2\frac{1}{2}$ „
D, Purlins, ...	$9 \times 5\frac{1}{2}$ inches.	9×6 „
E, King-post (oak), ...	8×4 „	5×4 „
F, Queen-posts (oak), ...	5×5 „	4×4 „
G, H, Inner struts, ...	$4\frac{3}{4} \times 3\frac{1}{2}$ „	4×4 „
I, Outer struts, ...	$3 \times 2\frac{1}{2}$ „	$4 \times 3\frac{1}{2}$ „
K, Cleets to do., ...	...	6×4 „

No. 2 shows the details of the king-post to a larger scale. The heads of the rafters and the feet of the struts are received by cast-iron sockets bolted to the king-post. The tie-beam is suspended to the post by an iron strap with wedges. A section through the tie-beam, king-post, and strap, is given at No. 3.

Nos. 4 and 5 show the scarfing of the purlins; and Nos. 6 and 7 the end of the tie-beam, with the iron shoe which receives the foot of the rafter, and the strap which secures it.

PLATE XXIV. *Fig.* 1.—No. 1, elevation of one of the principals of the roof of Wellington Street Church, Glasgow, designed by John Baird, Esq., architect, and erected in 1823. No. 2, part of the upper side of the tie-beam:—

A, Tie-beam, 12×9 inches.
B, Principal rafter, 13 ins. at bottom, 11 at top, and 9 inches thick.
C, Straining-beam, forming support of platform, and cambered, 13 ins. deep at centre, 11 at ends, and 9 inches thick.
D, Principal queen-posts, 13×9 ins. at top and bottom, and 9×9 in smallest part.
E, Second queen-posts, 10×9 ins. at top and bottom, and 7 by 9 in smallest part.
F, Principal strut, 9×9 inches.
G G, Secondary struts, 7×9 inches.
H, Straining piece between principal struts, 6×9 inches.
m m, Platform joists, $10 \times 2\frac{1}{2}$ inches, and 15 ins. apart from centre to centre, covered with boarding $1\frac{1}{4}$ inch thick for lead.
n n, Common rafters, laid horizontally, $6 \times 2\frac{1}{2}$ inches, covered with slate-boarding $\frac{7}{8}$ inch thick.

The principals are placed 9 feet 4 inches apart. All the timbers are joined by mortise-and-tenon joints. The platform joists and horizontal rafters are notched on the straining-beams and principals. The tie-beams are in two lengths of timber, scarfed, as shown in No. 2. The scarf is secured by iron straps, each 3 inches wide and $\frac{5}{8}$ inch thick, and bolted. The iron work is of the following dimensions:—

Straps at feet of principal rafters, $2\frac{1}{2} \times \frac{5}{8}$ inches.
Three-tailed straps connecting principal rafters, queen-posts, and straining-beam, $2\frac{1}{2} \times \frac{5}{8}$ inches; and each tail 2 feet 6 inches long.
Straps at feet of queen-posts, $2\frac{1}{2} \times \frac{1}{2}$ inch, bolted and keyed.
King-bolt $1\frac{1}{4}$ inch diameter, screwed up hard.

Fig. 2.—Elevation of a roof-principal of the parish church, Elgin, by Simpson of Aberdeen.

There are twelve principals similar to the elevation in *Fig.* 2. They are placed 6 feet 6 inches apart between centres; and the scantlings are as follows:—

A, Tie-beam, in two flitches, each $13 \times 5\frac{1}{2}$ inches.
B C, Principal rafters, 11 inches deep at lower end, 8 inches at top, and 6 inches thick.
D, Collar-beam, $7 \times 5\frac{1}{2}$ inches.
E, Struts, $5 \times 5\frac{1}{2}$ inches.
F, Struts, $5 \times 4\frac{1}{2}$ inches.
m m, Horizontal rafters, $4\frac{1}{2} \times 2\frac{1}{2}$ inches, 13 inches apart, and covered with groove-and-tongued deal 1 inch thick, and lead weighing 7 lbs. to the superficial foot.

The tie-beams have cast-iron shoes, H, at each end, with abutments formed for the rafters, and secured with $\frac{7}{8}$-inch diameter bolts, with nuts and washers.

The suspending rods are 1 inch square, and have abutment pieces for the rafters and struts.

Fig. 3.—One of the roof-principals of the City Hall, Glasgow. The following are the dimensions of its timbers:—

A, Tie-beam, 14×12 inches.
B, Cill piece, 12×12 inches.
C, Principal rafter, at the end, 9×7 inches, and at S, 11 inches deep.
D, Ditto, where doubled at lower end, 8×7 inches.
E, King-post, in two thicknesses, each 10×6 inches.
F, Queen-posts, at top and bottom, 13×7 inches, and in middle, 10×7 inches.
G, Straining-beam, 10×7 inches.
H, Struts, 6×6 inches.
K, Common rafters, $6 \times 2\frac{1}{2}$ inches.
m, Ridge board, 10×2 inches; batten over it, rounded for lead, $3\frac{1}{2} \times 3$ inches.
n, Wall-plates, under common rafters, $12 \times 1\frac{1}{2}$ inches, with pole-plate, 2×2 inches.
o o, Purlins, 8×5 inches.
p, Outer wall-plates, 14×3 inches.
r, Inner wall-plates, resting on corbels, 11×5 inches.

The iron straps are 4 inches broad by $\frac{3}{8}$ inch thick. Their bolts are $\frac{3}{4}$ inch square. The bolts securing the ends of the rafters, and the beams, are 1 inch square; and their washers are the full breadth of the beams.

The principals are placed 12 feet apart from centre to centre.

Fig. 4.—One of the principals of the roof of the East parish church, Aberdeen. The following are the dimensions of the timbers:—

There are five principal trusses, placed 14 feet apart.

A, Tie-beam, in two thicknesses, 14×10 inches.
Principal rafters, 13 inches deep at bottom, $11\frac{1}{2}$ inches at top, and $10\frac{1}{2}$ inches thick. The rafters bear on oak abutment pieces $11 \times 7\frac{1}{2}$ inches, bolted between the ties and to each other.
D, Collar-beam, in two thicknesses, one on each side of the rafter, and notched and bolted, $12 \times 5\frac{1}{2}$ inches each.
E, Purlins. The two lower, $13 \times 6\frac{1}{2}$ inches; the upper, $11\frac{1}{2} \times 8\frac{1}{2}$ inches; notched on the rafters and bolted.
F, Common rafters, $5\frac{1}{2} \times 2\frac{1}{2}$ inches, and 13 inches apart.

The discharging posts between the bracket pieces and the stone corbel are of oak, 6 inches square.

Binding pieces, $9\frac{1}{2} \times 3\frac{1}{2}$ inches, extend between the tie-beams, and are mortised into them; and into these binding pieces the ceiling joists, which are 13 inches apart, and $6 \times 1\frac{3}{4}$ inches, are mortised.

The dimensions of the iron work are as follows:—

King-rod, $1\frac{3}{4}$ in. square, with a cast-iron key piece at top.
Queen-rods, $1\frac{1}{2}$ in. square, having solid heads at rafters, and secured at foot by being passed through solid oak pieces *k*, placed between flitches of tie-beams, and securely bolted, and there fastened with cast-iron washers and nuts.

Four bolts at abutment end of ties, ...	$\frac{7}{8}$	inch	square.
Two do. at each oak piece, for suspending rods,	$\frac{7}{8}$	„	„
Two do. at each end of collar-beam, ...	$\frac{7}{8}$	„	„
Purlin bolts, ...	$\frac{3}{4}$	„	„

The abutments of the rafters at both ends, and the bearings of the bolts, have pieces of milled lead interposed; and all the joints of the framing were coated with white lead and oil before being put together.

PLATE XXV.—*Figs.* 1 and 2 show a wider use of iron in the parts of the framing acting as ties. They are the

roofs of sheds at the Liverpool Docks. The scantlings are as follows:—

Fig. 1.	Principal rafters, ...	12 × 8 inches.
	Struts, ...	8 × 8 „
	Purlins, ...	10 × 4 „
	Common rafters, ...	$4\frac{1}{2}$ × 2 „
	Tie-rod and suspending-rod, $1\frac{1}{2}$ inch diameter.	
Fig. 2.	Principals, ...	14 × 8 inches.
	Collar-pieces. ...	11 × 3, one on each side of rafter.
	Purlins, ...	16 × 4 inches.
	Tie-rods and suspending-rod, $1\frac{3}{4}$ inch diameter.	

The details are similar to those of the roof shown in *Figs.* 5, 6, 7, 8, 9, and 10 of the same plate.

Fig. 3.—A roof adapted to a hall or church with nave and aisles. The framing is simple and good:—

A, Principal tie. B, Tie of aisle roof.
C, Girder supported by the iron column D.
E, Story post.

Fig. 4 is a queen-post roof, adapted to the same use as the last.

Fig. 5.—Roof of the East Quay shed of the Salthouse Dock, Liverpool. Jesse Hartley, Esq., engineer.

The dimensions are all marked on the detailed drawings, which are made to a larger scale, and are contained in *Figs.* 6 to 10. The scantlings are as follows:—

Principal rafters, ...	16 × 9 inches.
Common rafters, ...	$4\frac{1}{2}$ × 2 „
Purlins, ...	15 × 5 „
Collar-beam, ...	15 × 9 „
Tie and suspending rods, 2 inches diameter.	

PLATE XXVI.—*Fig.* 1 shows the principal of a roof of 44 feet 8 inches span. In this, wrought-iron is used for the suspension rods, and cast-iron shoes as abutments for the timbers acting as struts.

At C, on the wall-head, is a cast-iron shoe, to receive the tie-beam and the foot of the principal rafter. The sole-plate of the shoe is prolonged, to admit of its being secured by bolts to the tie-beam.

The head of the principal rafter, and the end of the straining beam, are inserted into a cast-iron socket, an elevation of which is seen, enlarged, at No. 1. The suspension rod A D, it will be seen, passes through the solid part of the socket. It has a head at its upper end, and at its lower end it is screwed, and secured by a nut. On the side of the socket is cast a rest for the end of the purlin *a b*. To avoid cutting the principal rafters, the other purlin at B is also carried in a cast-iron rest bolted to the rafter. The centre suspending rod at E passes through a cast-iron socket, which serves as an abutment to the two main struts. Similar abutments are provided for the lower end of the struts.

Fig. 2.—This principal, for a roof of 45 feet span, has details of the same kind as those described above. The detail No. 2 is a section of the shoe at head of king-bolt, into which upper ends of principals are inserted.

Fig. 3.—This is a principal also with wrought-iron suspension rods. The tie-beams, principals, and struts are first framed together; the suspending rods are then introduced, and screwed up by the nuts at their lower end until the framing is firmly united. A roof of this construction, 54 feet span and 212 feet long, is erected at the passengers' shed of the Croydon railway station.

Fig. 4 shows a roof, the principal rafters of which are constructed of timber and iron. They are in three thicknesses, the centre flitch being timber, and the side plates wrought-iron, bolted together through the timber, as shown more at large in the section No. 7. No. 3 shows the foot of one of the rafters, with the iron girder on which it is supported; the mode of attaching the tension-rod, and the manner of constructing the gutter. No. 4 shows the cast-iron strut at B. No. 8 is a section of the rib of the strut on the line A. Nos. 5 and 6 show, in plan and elevation, the manner of connecting the tension-rods at the apex; the letters refer to the same parts in both.

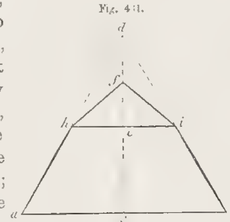
Fig. 5 is a roof-principal, formed with iron rafters, struts, straining-beam, queen-posts, purlins, and tension-rod. The iron parts are connected together by hinge-joints, as at C. The purlins are supported by sockets on the principals, as at B. The common rafters are of timber.

PLATE XXVII.—To diminish the excessive height of roofs, their sharp summit is suppressed, and replaced by a roof of a lower slope.

Francis Mansard, who died in 1666, brought this sort of roof into fashion in France, and was for a long time regarded as its inventor.* The roof is known, indeed, as the Mansard roof; and the garrets formed in such roofs were called *Mansards*. The Mansard roof may be described in several manners:—

1st. In Fig. 461, the triangle *a d b* represents the profile of a high-pitched roof, the height being equal to the base. At the point *e*, in the middle of the height *c d*, draw a line horizontally *h e i*, parallel to the base *a b*, to represent the upper side of the tie-beam, and make *e f* equal to the half of *e d*; then *a h f i b* will be the profile of the Mansard roof.

Fig. 461.



2d. In Fig. 462, make *c e* the height of the true roof, equal to half the width *a b*, and construct the two squares *a d e c*, *c e g b*; also make *d h*, *e f*, and *g i* each equal to one-third of the side of a square; then will *a h f i b* be the profile required.

Fig. 462.

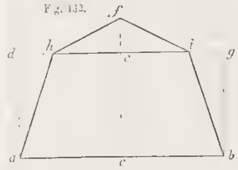
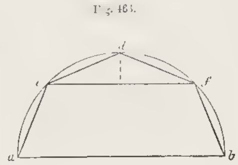


Fig. 463.

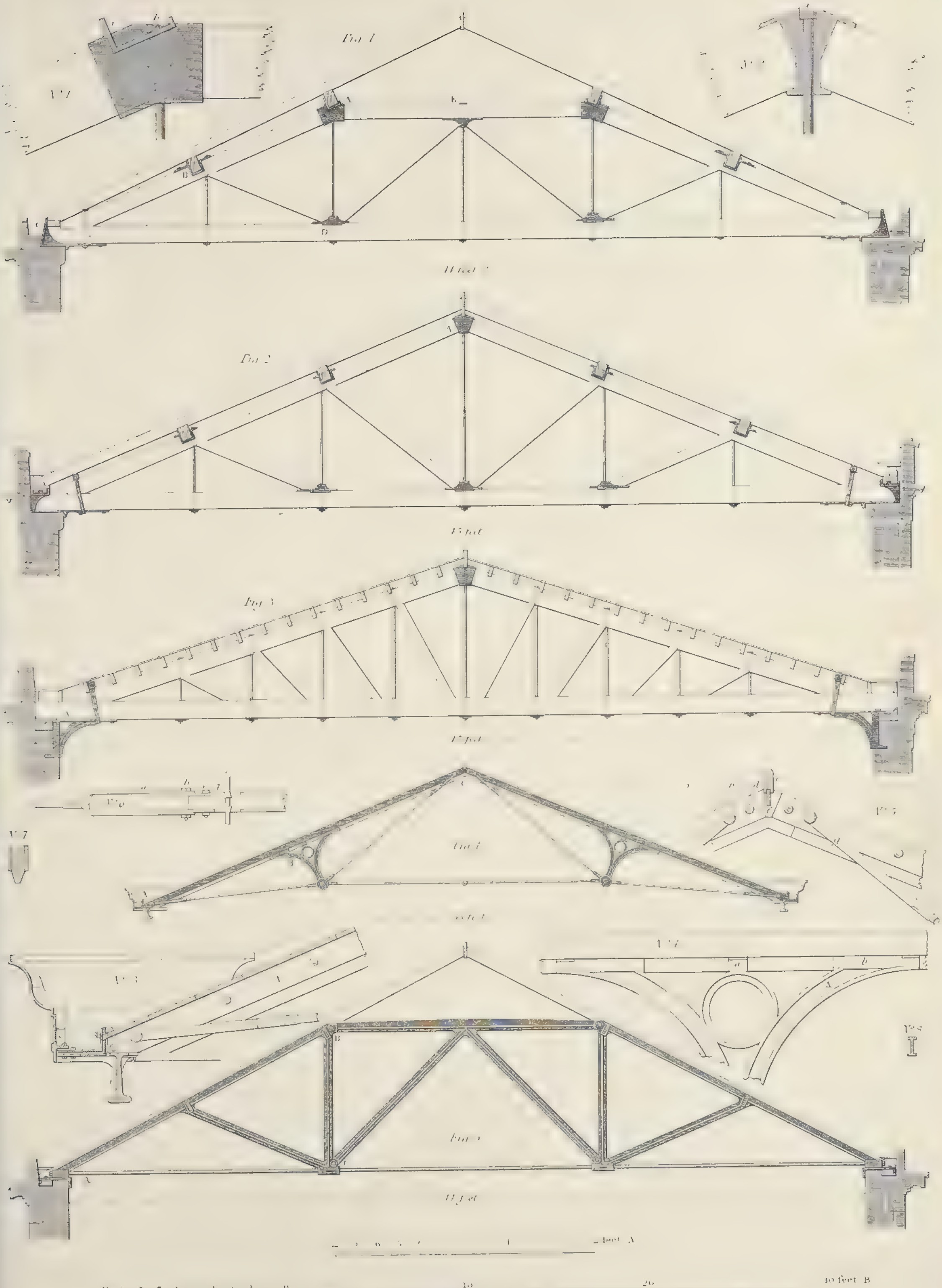


3d. In Fig. 463, on the base *a b*, draw the semicircle *a d b*, and divide it into four equal parts, *a e*, *e d*, *d f*, *f b*; join the points of division, and the resulting demi-octagon is the profile required.

4th. Fig. 464.—Whatever be the height of the Man-

* Bullet says that Mansard truncated his roofs after the example of one at Chilly, by Metezeau. Mesanges asserts that he took the idea from a frame composed by Segallo, and that Michael Angelo employed it in the construction of the dome of St. Peter's; but Krafft, in his work on *Carpentry*, seeks a more remote origin for this kind of roof. He remarks that it existed in the Louvre, built by Pierre Lescot for Henri II., in 1570. He adds, that the houses in Lower Brittany were covered with these roofs in the end of the fifteenth century.

ROOFS.

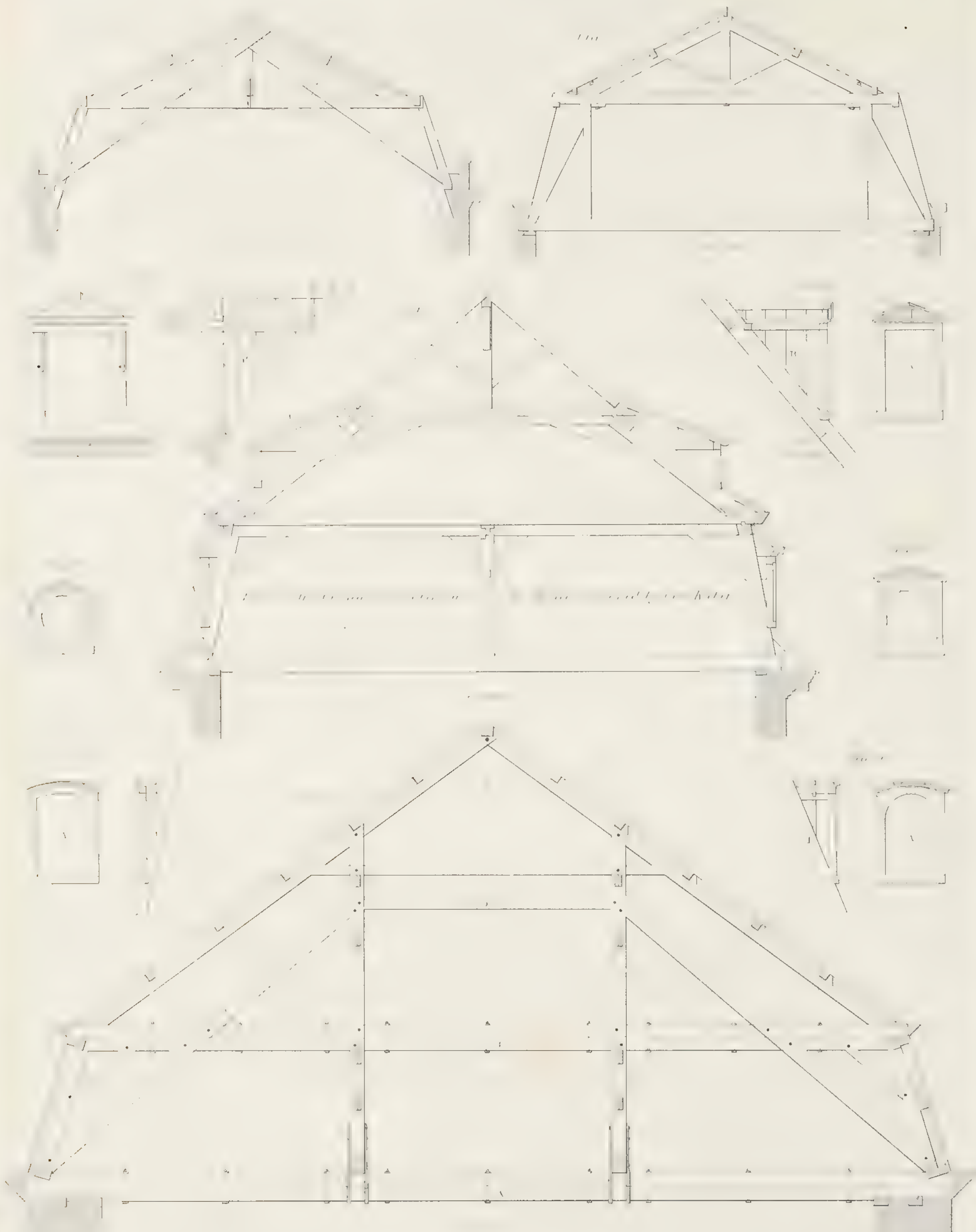


J. White, del.

J. W. Lowry, fc.

ROOFS.

CURB OR MANSARD ROOFS AND DORMERS



sard, $c\ e$ or $b\ g$, D'Aviler makes $g\ i$ equal to the half of that height; and the height, $e\ f$, of the false roof, equal to the half of $e\ i$.

5th. Fig. 465.—Describe the semicircle $a\ f\ b$, and

Fig. 464.

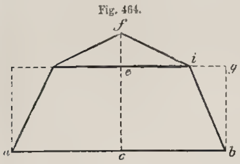
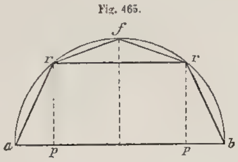


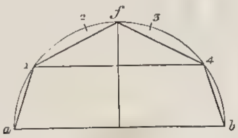
Fig. 465.



divide each half of the base $a\ b$ into three equal parts. From the last divisions $p\ p$, the perpendiculars $p\ r$, $p\ r$ are erected, cutting the semicircle in $r\ r$; then $a\ r\ f\ r\ b$ is the profile.

6th. Fig. 466. — This method, which is described by Beledor in *La Science des Engineurs*, has been generally adopted on account of its simplicity, and the good effect which it produces.

Fig. 466.



Describe a semicircle on the base $a\ b$, and divide its circumference into five equal parts, in 1 2 3 4; then the chords a 1, b 4 are the sides of the true roof, and 1 f, 4 f those of the false roof. It is by this method that the lines in *Fig.* 1, Plate XXVII., are set out.

The forms of the Mansard roof, it will be seen, may be infinitely varied, by choosing, in the diameter or in the semi-circumference, other points of division, or by altering the relation between the height and width of the roof, according to the uses to which it is to be converted.

Plate XXVII., *Fig.* 1.—A Mansard roof for an arched ceiling, selected from Krafft.

Fig. 2.—A king-post Mansard roof. In this example there is a wide space available as an apartment. The construction would be improved by adding straps to the feet of the story-posts.

Fig. 3.—A roof with two stories of apartments in its height. This is an example also taken from Krafft. It is the roof of the Chateau de Florimont, in Alsace, designed by General Kleber. It is difficult to conceive what good is obtained by the introduction of the story-post in the centre.

Fig. 4.—A queen-post Mansard roof. This is regularly trussed, and is erected over the riding-house at Copenhagen. Colonel Emy remarks that there should be struts a under the purlins, and a small collar-piece b added; that the tie B is too heavy, and that the cross-piece above D serves no useful purpose, and might be dispensed with.

Figs. 5 to 10, on the same plate, are examples of the modes of forming and framing dormers, such as at A and B, in *Fig.* 3.

When Colonel Emy was called upon, in 1819, to construct the roof of a building upwards of 60 feet wide, at the barracks of Libourne, it was proposed to him to follow the method of De Lorme, a notice of whose system is prefixed to the description of Plate XXX. But, while acknowledging the merit of De Lorme, and the beauty of the results obtained in constructing roofs in accordance with his method, it had yet appeared to M. Emy, that where timber of tolerable length could be obtained, results equally good might be produced, without cutting it into the short scantlings required by De Lorme's system.

Accordingly, as the country afforded pines of from 36 to 40 feet long, and fir still longer could be easily obtained from the Pyrenees, he sought to compose a roof in which the timber might be used in its whole length, and which should combine the necessary solidity with the lightness, elegance, and economy of the system of De Lorme. He succeeded in designing a roof which, in his judgment, satisfied all those conditions; but did not obtain authority to carry out his designs. He was authorized at length to make a trial at Marac, near Bayonne, in 1825, in roofing a building of nearly the same dimensions. The success of this trial was such as, in 1826, determined the authorities to roof, in the same manner, the manege at Libourne, for which the system was originally designed.

The execution of M. Emy's system is within the power of the ordinary carpenter; and the workmanship is less than in the roofs of De Lorme, as the wood is all in straight pieces. There are neither mortises nor tenons, except at the ridge; and the process of construction and setting the principals in their places is so simple, that, as M. Emy says, twelve workmen, two-thirds of whom were common labourers, were able to put together, and raise and set in their places, two principals each week at Marac.

Principals have often been constructed of great arcs, or centres, formed of several pieces of timber superimposed on each other. But such pieces have been of considerable scantling. They have been very short; their connection has been by iron; and their curvature produced by the adze or by heat. Now, the construction invented by M. Emy is a timber arch composed of a series of long and thin planks applied on the flat, the flexibility of which permits them to be easily and quickly bent without the aid of heat; and their rigidity, properly regulated, has the property of maintaining the form given, and destroying the thrust.

It would be impossible to bend, even with the aid of fire, timbers of the same scantling as these composite arcs. Even supposing that pieces of half the length could be so bent, then, to form the whole arch, butt-joints, occupying the whole section of the timber, would have to be introduced; while, by building these arch-beams of thin planks, the joints can be properly broken without weakening the strength of the beam.

The combination of this system may be varied infinitely by the number, the span, and form of the arcs; and the strength of the arcs may be increased, according to the necessity of the case, without changing the system, or injuring the elegance of its appearance, by simply adding more planks either to the whole length of the arc, or to such part as trial, always indispensable in large constructions, shows to be necessary.

Since the invention of M. Emy has been made public by his own publications, and by the report of the Society for the Encouragement of National Industry, in March, 1831, roofs have been constructed on his principle with great success both for large and small spans. The examples we have engraved embrace the roof of a shed at Marac, and the roof of the riding-house at Libourne, constructed by himself (Plate XXVIII.); and the application of his system to the roof of a Gothic church erected

at Grassendale, near Liverpool, by Mr. Arthur Hill Holme, architect (Plate XXIX.)

PLATE XXVIII.—Roof of a shed at Marac, near Bayonne, France.

Each principal of this roof (*Fig.* 1) is composed of a semicircular arch, two principal vertical pieces, two principal rafters, two struts, a king-post, and a collar-beam, the whole tied together by pieces which are at right angles to the curve. These radial pieces, as well as the sides of the arch, are notched upon each other.

The vertical pieces are distant from the face of the wall about 4 inches. The three first radial pieces on each side are prolonged beyond the uprights, and enter recesses made in the wall to receive them, as seen in *Fig.* 12. The object of this is merely to steady the frames, and keep them vertical.

Between the radial pieces, the plates composing the arc are bolted together with cylindrical bolts, which are driven tightly into accurately made holes by a heavy mallet. These keep the plates from sliding on each other. The plates are further firmly tied together by iron straps. The bolts are $\frac{7}{16}$ inch diameter, and about 2 feet 6 inches apart.

The plates of wood forming the arc are $1\frac{3}{8}$ inch thick, $5\frac{1}{16}$ inches broad, and about 40 feet long. Two and a half plates of this length, joined end to end, make up the whole length of the curve. The joints are so distributed that those of one row do not correspond to those of another row, and that each joint is carried by one of the radial pieces. All the plates cannot, of course, have only three joints; and several of them have only two. Thus there may be only from ten to twelve joints in the whole arc.

The vertical pieces are $7\frac{3}{4}$ inches thick; the principal rafters $5\frac{1}{4}$ inches thick.

The principals are placed 9 feet 10 inches apart; and maintained in this position by the braces seen in *Fig.* 2, and on a larger scale in *Fig.* 6, by the purlins, and by a line of double ties stretching between the fourth radial pieces.

When this roof was proposed, it was alleged that it would alter its form, and exercise a thrust upon the walls, especially when loaded with its covering. Colonel Emy, therefore, judged it proper to make several experimental principals on this construction, which could be submitted to proof, and enable him to determine what weight they could support without alteration of form, and also the number of plates of which the arcs should be composed. The experimental arcs were composed of five plates. They were sustained by thick plates of oak laid on the ground, which had first been truly levelled and beaten solid. When the arc was raised up and left to itself it drooped a little.

Then, by long cords, there were suspended to the points of the arc, which represented fairly the points of pressure, platforms of wood at about 20 inches above the ground. These platforms were then loaded gradually with cast-iron, until the weight on each reached 2200 lbs., making the total load 10·8 tons — a weight which was one quarter more than the principal would have to sustain. The plates in these experimental arcs were fastened together solely by the radial pieces and iron straps, as Colonel Emy wished to reserve a means of increasing the strength by inserting the bolts after the experiment, and when the principals were set in the places they were finally to occupy.

As the weights were added, the arc appeared to flatten. At the end of twenty-four hours, its curvature was tested by a radial rod of wood of 32·8 feet long mounted with iron at each end, and centred truly on an iron axis, and established with precision on the head of a pile driven in to the level of the springing of the arch. It was found that the king-post had fallen down, but that the curvature of the arc comprehended between the seventh radial pieces had not sensibly altered. There was an augmentation of the curvature below these points, the maximum being at radial No. 4; and the disposition of the principal rafters and uprights was, of course, also slightly affected. The diameter of the arc, however, did not vary; and therefore the plates must have slid on each other to the extent of not quite an eighth of an inch each.

The conclusion derived from the experiments was, that the stiffness of the arc should not be the same throughout, and that it was necessary to reinforce it in the places that had yielded the most, by supplementary plates. The proper result was obtained by adding, on the two sides of each arch, one supplementary plate to a part of the extrados, and two plates to a part of the intrados. The following is the proportion of the number of plates, and their width, which Colonel Emy adopted as a rule:—

			Width. Ft.	In.
From the springing to radial No. 1, ...	7 plates,	...	1	3
From radial No. 1 to the tie placed between radials Nos. 6 and 7, ...	8 ,,	...	1	7
From the above tie to radial No. 9, ...	6 ,,	...	1	0
From radial No. 9 to king-post, ...	5 ,,	(nearly)	0	11

The supplementary plates were of oak, and of the same thickness as the others.

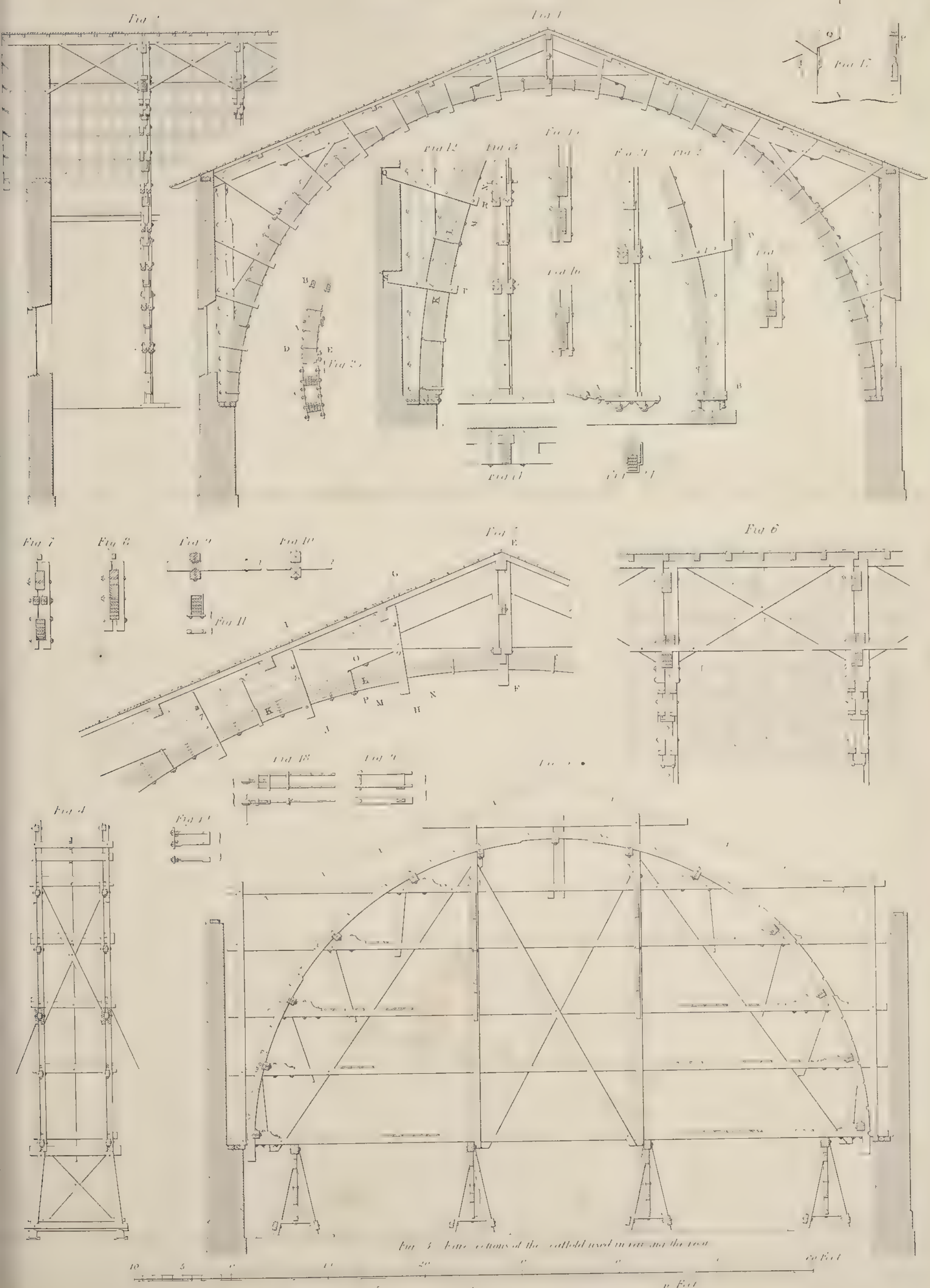
The principals thus strengthened were again submitted to proof without change of form.

The manner of constructing the principals was as follows:—The ground having been dressed and beaten to a level, a semicircle of 65 feet 7 inches diameter was described, representing the intrados of the arc of five plates; and the chief lines of the principal were then traced, and strong sleepers were laid down and fastened by pickets. The sleepers, twenty-four in number, and 10 inches square in section, were all laid radially, and distributed so as to fall between the radial pieces of the arc and the iron straps; two only were on the outside of the springing. On these sleepers a floor was laid large enough to hold the draught of the principal; and the centre of the arc was formed by an iron axis fixed on the head of a pile. The floor being laid, and the draught made on it, pieces of wood 8 inches square were fastened through it by long spikes to the sleepers, and to these the template for curving the plates forming the arc was fixed. The process of bending timber for this and similar purposes has already been described in detail at pages 102, 103, substituting a continuous template for the polygon. To this the reader is referred.

The arc being formed by the process there described, the other parts of the principal were properly fitted, but not fastened; and on being completed, the parts were taken asunder, numbered, and put aside, to be raised to their places on the completion of the whole. This was necessary,

ROOFS.

ROOF OF A SHED AT MARAC NEAR BAYONNE FRANCE



ROOFS

PLATE XXIV

ROOF OF THE SALLE DES CATECHISMES CATHEDRAL OF AMIENS. *Figs. 1. 2. and details.*
ROOF OF GRASSENDALE CHURCH *Figs. 3. 4. and details.*

Scale to Figs. 1 and 2

Scale to Figs. 3 and 4

Jones, del

as Colonel Emy found himself unable to raise the principal entire.

The erecting the principals in their places on the walls was thus accomplished:—A moveable scaffold was prepared, easily erected and removed, and provided with a template similar to the one on which the arc was formed. This is shown in *Figs.* 3 and 4.

When the scaffold was brought exactly to the place where the principal was to be erected, all the pieces of the latter were raised as numbered, and put in their places; and then, when completely fastened together, the template or centre was detached, and the arc allowed to rest on its wall-plates. The bolts were then added to the arc before it received the weight of the roof timbers. Colonel Emy considered, after completing his work in the way described, that he might have constructed the arcs, and fitted all the pieces on the vertical template at once, and thus have saved time, and made the work more perfect; but the idea came too late.

The principal being thus placed, was maintained in its position by wedges, the ends of the radials, in the recesses in the walls before mentioned, and by stays nailed to the principals temporarily; and the scaffold was removed to the place of the next principal.

We shall now describe particularly the figures on the plate.

Fig. 1.—Transverse section of the building, and elevation of one of the principals.

Fig. 2.—Longitudinal section.

Fig. 3.—Transverse section of the building before the placing of the principals, and section of the scaffold.

Fig. 4.—Section of the scaffold, at right angles to the preceding.

Fig. 5.—Elevation of the summit of the principal in *Fig.* 1 drawn to a larger scale.

Fig. 6.—Section through E F of *Fig.* 5, showing the counter-bracing and ties between the principals.

Fig. 7.—Section on the line G H of *Fig.* 5.

Fig. 8.—Section on the line I J of *Fig.* 5.

Fig. 9.—Section of one of the radials on the line K L, *Fig.* 5, corresponding to the longitudinal point of the arc.

Fig. 10.—End elevation on the plane M N of the radial No. 9.

Fig. 11.—Section through the arc on the line O P, showing one of the iron straps.

Fig. 12.—Side elevation of the springing of one of the arcs, showing two of the radials Q R, S T, and the recesses, Q and S, in the wall, to receive their prolongations.

Fig. 13.—Front elevation of the same.

Fig. 14.—Portion of the plan of the wall-plates, showing the manner in which the parts of the principal are framed into them.

Fig. 15.—Section of the principal on the line of the upper face of the radial No. 2, Q R, *Fig.* 12.

Fig. 16.—Section of the principal on the line of the upper face of the radial No. 1, S T, *Fig.* 12.

Fig. 17.—Junction of the upright and principal rafter: Q is the elevation; P is the profile on the line U V. For the sake of distinctness, the radial is not shown.

Fig. 18.—Iron strap and screw used in bending the arc plates.

Fig. 19.—One of the straps used in securing the plates to the template.

Fig. 20.—One of the ties of timber serving the same purpose.

Figs. 21 to 24 are parts of the roof of the riding-house at Libourne.

This roof, on the same principle, was erected in 1826. The principals differ from those of Marac, just described, in this: that as the walls at Libourne were of great thickness, and strengthened by great counterforts, it was not necessary so carefully to guard against lateral thrust, and therefore the arcs were composed of fewer plates each throughout.

The diameter of the intrados of the arcs is 68 feet 8 inches; the principals are placed 10 feet 6 inches apart, from centre to centre.

In constructing these principals, a working floor was erected at about 2 inches below the wall-plate, and the draught was laid down on it, and a polygonal mould was formed in the manner described at pages 102, 103. This, as remarked at that place, is not so perfect as the continuous template, such as was used at Marac, and is more apt to rupture the wood at the points of contact, unless it is freshly cut and very flexible.

The floor on which the principals were constructed extended only half the length of the building; therefore, although the principals were easily raised to the vertical position, by the application of shears and windlasses, each had to be moved to its proper place. This was effected by placing under each springing a little carriage running on the wall-plates. The frames were kept upright by proper stays, and the carriages dragged along by tackling, and forced by levers till they reached their places.

Figs. 21 and 22.—Front and side elevations of the springing of one of the principals. The centre of the arc is on the line A B. The principal is mounted on one of the carriages mentioned above.

Fig. 23.—Section through the principal on the line C D.

Fig. 24.—Horizontal section on the line A B.

PLATE XXIX.—*Fig.* 1. Roof of the Salle des Catechismes, Amiens Cathedral. *Fig.* 1 is a transverse, and *Fig.* 2 a longitudinal section of this roof. It is composed of principals formed with principal rafters, curved ribs, king-post, tie-beam, and collar-beam. The ends of the tie-beam, in addition to their wall-hold, are supported by framed brackets, resting on stone corbels in the wall. The brackets, tie-beam, king-post, and curved ribs are all exposed to view, and are moulded in a very simple and effective manner. The ceiling is vaulted, and formed of boarding, ornamented with vertical moulded ribs, placed about 18 inches apart.

Fig. 1.—No. 1 is an elevation of the lower portion of the king-post, showing the mode of finishing the chamfering. No. 2 is a section through the octagonal portion of the post. No. 3 is a vertical section of the tie-beam. No. 4 is a section of the cornice from which the arched ceiling springs.

Fig. 3 is the elevation, and *Fig.* 4 the longitudinal section of a Gothic roof on Col. Emy's principle, designed by Mr. Arthur Hill Holme, of Liverpool, and erected under his direction at Grassendale Church, Aigburth; and Nos. 1, 2, and 3, *Fig.* 3, are the details of the same roof drawn to a larger scale. The mode of construction was in every respect similar to what has already been described, and need not therefore be repeated.

In 1561, Philibert de Lorme published his book, entitled *New Inventions for Building Well at Little Expense.*

In his address to the reader, he says, among other things, that as it is difficult to find trees large enough to serve for beams, and the other timbers of mansions, he has long sought for some invention which would enable him to use all kinds of wood, and even the small pieces, and so to dispense with the great trees hitherto used. The result of his researches was the system of framing to which the name of the inventor is given, and which is here illustrated and described in detail.

The system of Philibert de Lorme is composed of arcs or hemicycles formed of planks, used as substitutes for the framed principal.

The planks forming one layer or thickness are placed end to end, and their joints are cut radially to the centre. The joints of one layer or thickness of plank correspond to the middle of the planks of the second layer, and for small spans each plank is only about 4 feet long, by about 8 inches wide and 1 inch thick. The feet of the hemicycles are tenoned into the wall-plates. The shoulders of the tenons are about 1 inch.

The hemicycles are all traversed in the joints by ties 1 inch thick and 4 inches wide. Keys of 1 inch thick and $1\frac{1}{2}$ inch wide, and of a length nearly equal to the width of the planks, traverse the ties. They serve to maintain the hemicycles in their vertical planes at their proper distance apart, which is about 2 feet, and, at the same time, to tie, in each hemicycle, the planks together. The mortices in the ties are a little less apart than twice the thickness of the rib-planks. Some make only one mortice, with the view of saving labour.

The mode of construction illustrated by all the figures in Plate XXX., was first employed by De Lorme in roofing the pavilions of the Château de la Muette, at St. Germains-en-Laye. The walls of these pavilions were in a defective state, and would not bear the weight either of stone vaulting, or of heavy carpentry, even if trees large enough to make the roof of the ordinary construction in use at that time could have been obtained, which, we learn from the work of De Lorme, published in 1561, was not the case.

The advantage of the system, according to its author, is the saving of expense, because very light and short timbers are proper for the work, and the walls need not be so thick as for heavier carpentry; great vehicles for the transportation of the wood, and ropes and engines for the raising it, are not required; and in countries where only small scantlings of timber are obtainable, it permits of roofs of greater span to be made than would otherwise be possible.

In Plate XXX., fig. 5 shows a portion of one of the hemicycles, as he called his frames, for spans of from 24 to 30 feet. Each hemicycle, A B, in this case, is built of two thicknesses of wood, each of which, *e f*, is in pieces of 3 or 4 feet long, 8 inches wide, and 1 inch thick. The joints of the one series are made to fall on the middle of the length of the other; each piece has a mortice cut in the middle of its length, and a half-mortice at each end. The mortices are 4 inches long, and a little more than 1 inch wide. They serve to receive ties *g g*, which may be of any length, and otherwise of the same dimensions as the mortice. The ties are secured in their places by keys *h h*, driven through mortices made in the ties, one on each side of every hemicycle. The mortices in the ties are made with a little *draw.* The keys are best when made of split wood. The two thicknesses of timber in each hemicycle are first framed together by small pins, to prevent their sliding, and then the hemicycles are united by their ties, and the two fastened by the keys. They are then placed on wall-plates, 10 or 12 inches wide, and 8 or 9 inches thick, having mortices sunk at 2 feet apart to receive the ends of the hemicycles. The mortices are 2 inches wide, 3 inches deep, and 6 inches long.

In the roof of the pavilion of the Château de la Muette, where the span was 64 feet, the scantling was increased to 13 inches wide, and $1\frac{1}{2}$ inch thick. The ties were alternately double and single, and were 3 inches by $1\frac{1}{2}$ inch. Each hemicycle was double tenoned into the wall-plate. The general elevation of the roof is shown in *Fig.* 1, and parts of the hemicycles to a larger scale in *Fig.* 6. The same letters refer to the same parts in both figures—A A, one of the hemicycles; B, a terrace or gallery, used as a belvidere; *c c*, double ties; *d d*, single ties; *e e*, wall-plates; *f f*, eaves-rafters (coyaux). The notches for double ties are just so deep, that the outside surface of the tie is flush with the edge of the hemicycle.

When the span is small, and the curve of the roof is so quick that it becomes impossible to cover it with slates or tiles, De Lorme adopts the expedient shown in *Figs.* 2 and 3.

Fig. 4 shows the application of the principle in the construction of a groined vault, with a pendant in the centre. The dimensions of the pieces of which these arcs or hemicycles are composed, increase of course with the increase of the span of the arch; and, as has been mentioned above, the single ties give place to double and single ties placed alternately. In the roofs of ordinary buildings, where the span does not exceed 24 feet, the author directs the pieces which compose the hemicycles to be made 1 inch thick and 4 feet long; for roofs of 36 feet span, the thickness to be $1\frac{1}{2}$ inch; for roofs of 60 feet, the thickness to be 2 inches; for roofs of 90 feet, the thickness to be $2\frac{1}{2}$ inches; and for roofs of greater dimensions, the thickness to be 3 inches.

PLATE XXXI.—Roof of the great hall, Hampton Court.

Fig. 1 is a longitudinal, and *Fig.* 2 a transverse section of the roof. The great hall at Hampton Court is 106 feet long, 40 feet wide, and 45 feet high in the walls. It was completed in 1536 or 1537. The roof consists of seven bays in length, one of which is the subject of *Fig.* 1, and by referring to the transverse section, *Fig.* 2, the construction, which is similar to that of Westminster Hall, will be clearly comprehended. Each principal consists of a centre arch and two half-arches, and the principals are connected by three tiers of arches, as seen in *Fig.* 1. These, with their enriched panels and pendants, produce an exquisite richness of effect.

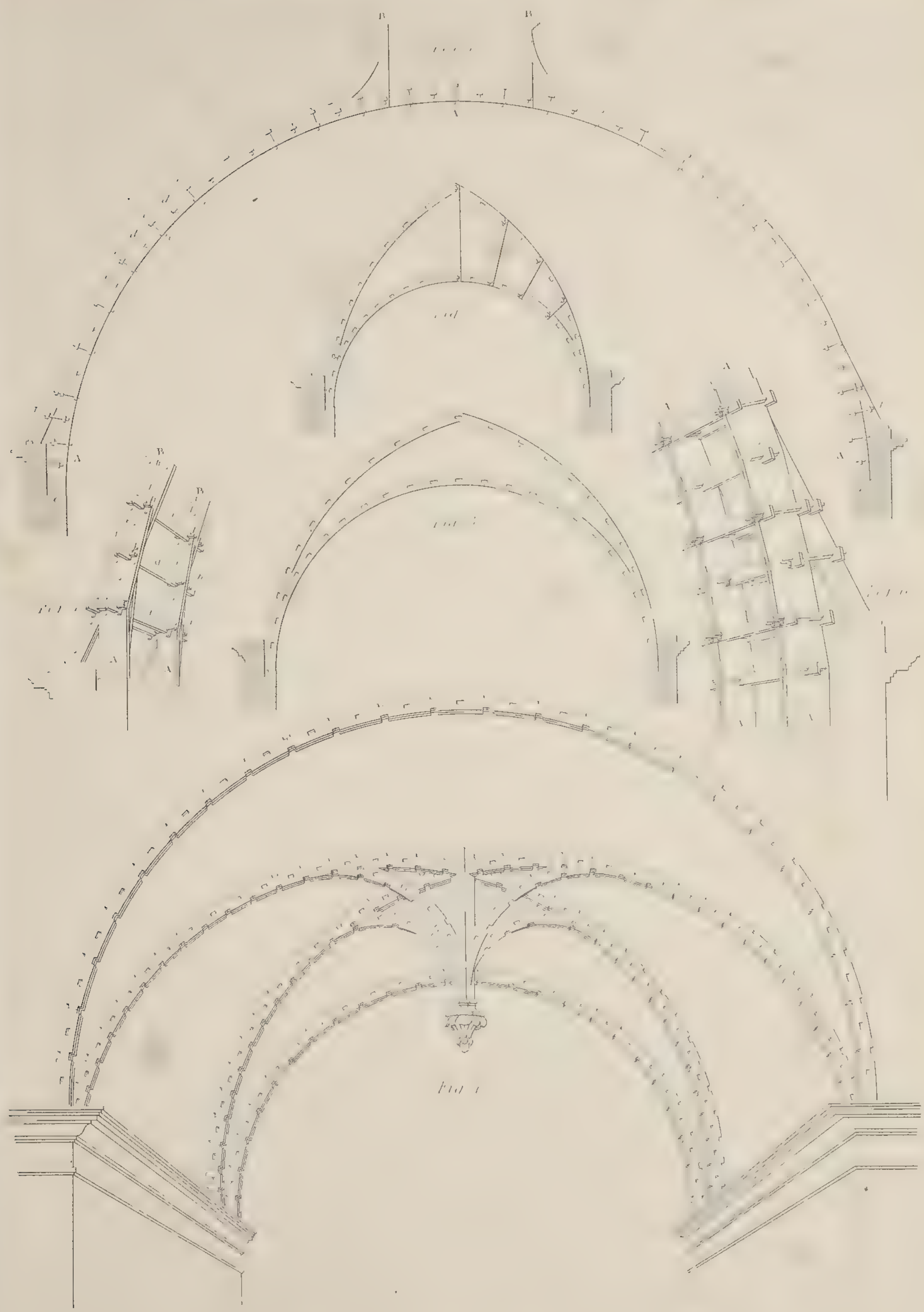
Fig. 4 is one of the large pendants.

Fig. 3.—One of the pendants of the second tier of arches.

Fig. 6.—One of the pendants of the third tier of arches.

Figs. 7 and 8 are two of the wall-corbels from which the roof springs. The exterior of the roof has a double pitch like the Mansard roof.

DOMED ROOFS ON THE SYSTEM OF PHILIBERT DE L'ORME



ROOFS.

ROOF OF THE GREAT HALL, HAMPTON COURT

10 5 0 10 20 Feet

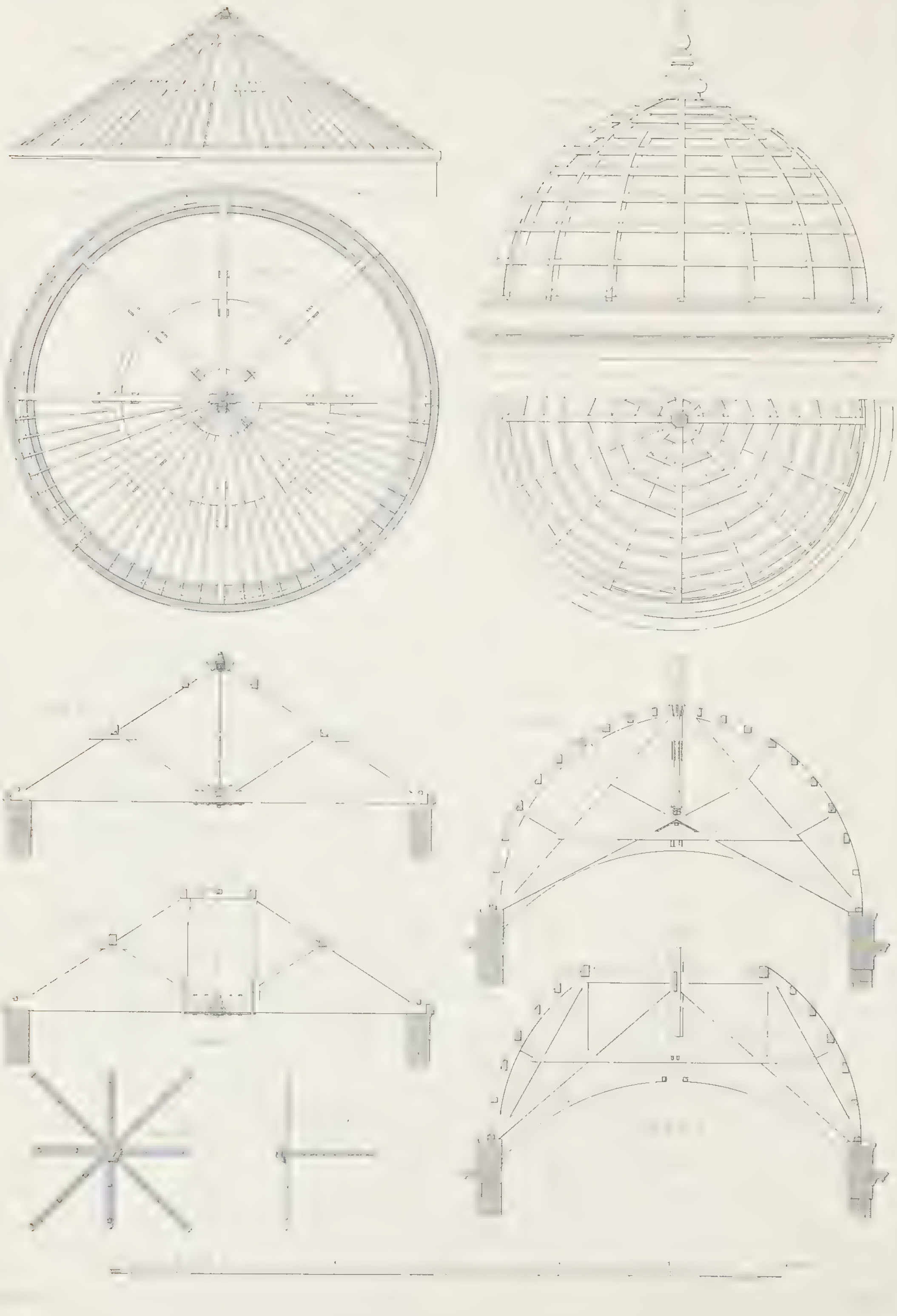
W. A. Beever Sc.

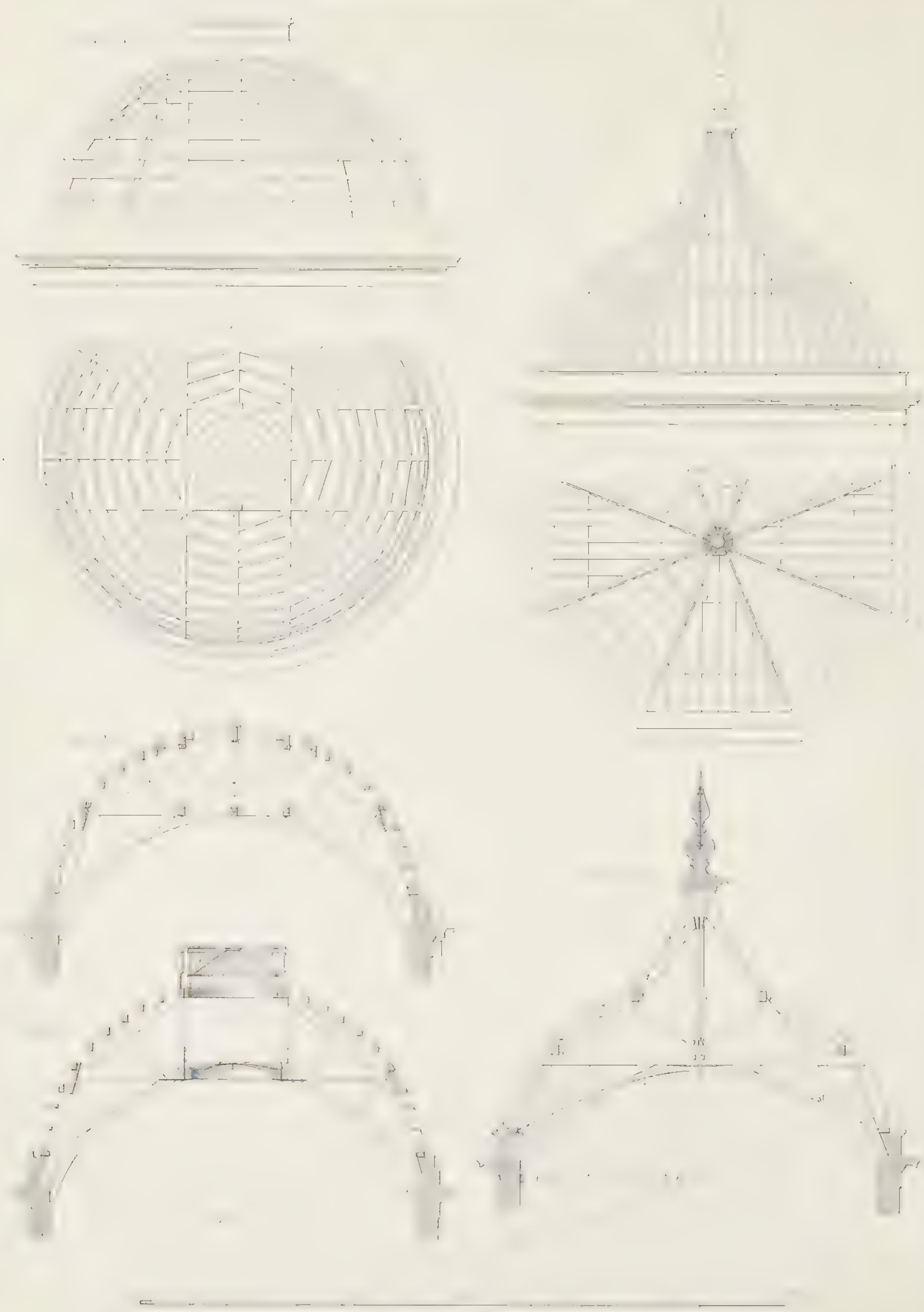
ROOFS.

PLATE XXVII

ROOF OF WESTMINSTER HALL

J. White del.[t]





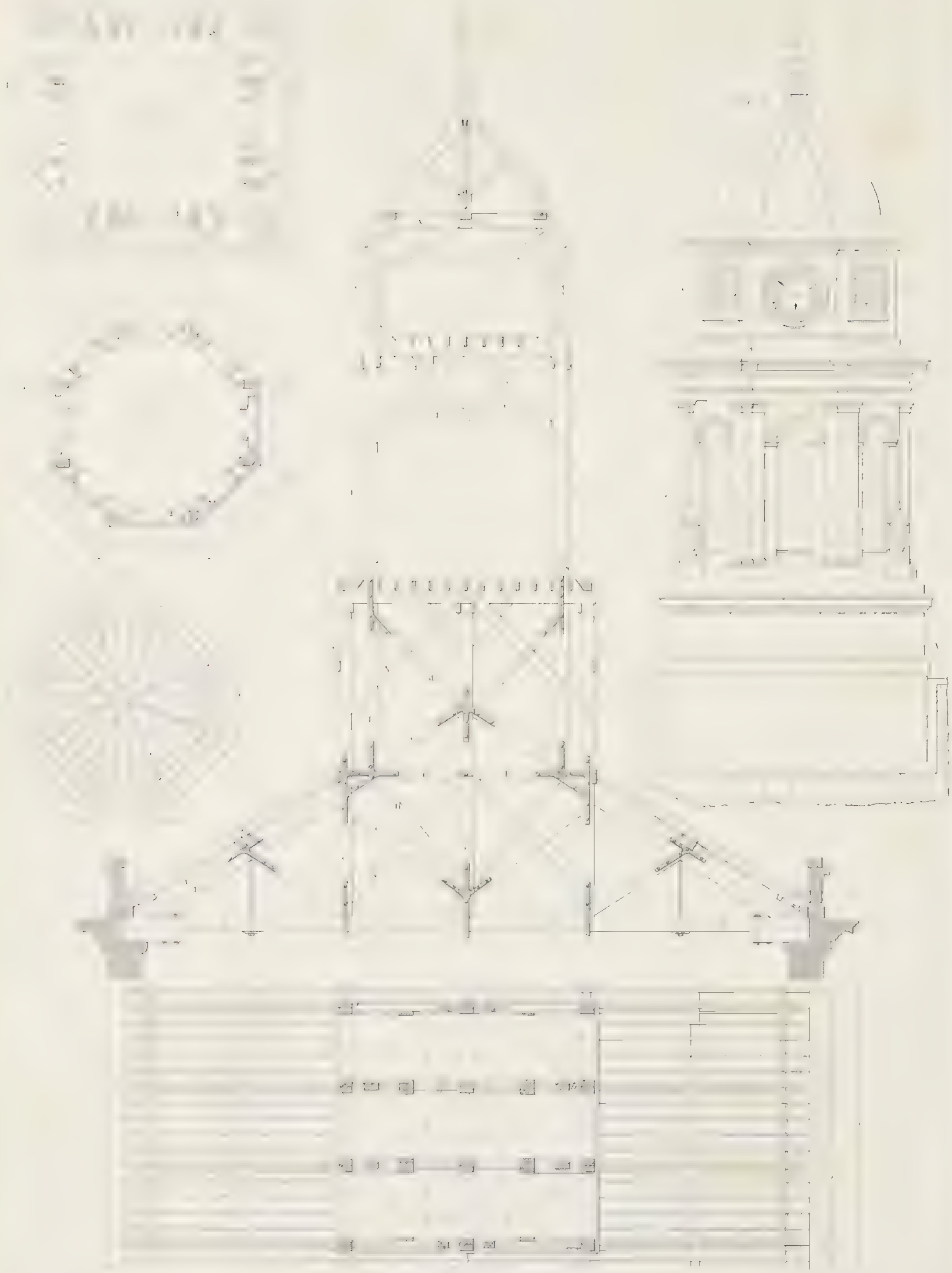


PLATE XXXII.—The figures in this plate represent the roof of Westminster Hall. This noble hall was first built in the reign of William Rufus, in the beginning of the eleventh century; but, 300 years afterwards, was rebuilt by Richard II.; and in 1399, the festivals of Christmas were celebrated in it, by banquets of extraordinary magnificence.

In *Fig.* 1 is shown the half of one of the principals. It is composed of two rafters *a a*, joining at the apex on a punchion, and united in the middle of their length by a collar-beam *d*. There is no tie-beam, but, in its place, two hammer-beams *e*, one at each side, which receive the ends of the rafters. These hammer-beams are horizontal, and are sustained by the arc *f*. The end of each hammer-beam sustains a post *g*, decorated with a base and capital, and into this post is framed the rafter or strut *c*, which discharges part of the weight, and is supported at the foot on a block *h*, lying on the inner end of the hammer-beam. It is prolonged below the hammer-beam at *i*, and abuts against a stile placed on the wall. Between the collar-beam and the ridge there is another beam *k*, framed into the posts *n*, which sustain the rafters at the point where the purlins *o* rest. A great arc *m* springs from the same corbel as the bracket of the hammer-beam at the middle of the height of the walls. This arc is in two pieces, and embraces in its thickness the posts *g* and the collar-beam *d*. Another lesser arc *r* springs from the end of the hammer-beam, and joins the great arc. This discharges part of the framing to the point of the beam, whence it is carried by the lower arc to the corbel. These parts are all connected and firmly braced together, and to the rafter, by the iron rod *l*, which passes through them, and is secured by a screw and nut at the under side of the last-mentioned arc under the hammer-beam.

Fig. 2 is a longitudinal section of one bay of the roof comprised betwixt two principals. The roof, it will be seen, is in three divisions: the first, rising from the cornice, terminates at the hammer-beam; the second extends from the hammer-beam to the collar-beam; and the third from that to the ridge. Curved pieces *w t x* are introduced to support the timbers longitudinally; and a collar-beam is introduced between the common rafters, to prevent them sagging under the weight of the covering, and they are further strutted by the pieces *u u*. The lower purlins *p* of the roof are also sustained by two curved struts *y* abutting against the great arc.

Figs. 3 and 4 are representations, to a larger scale, of the angels sculptured at the extremity of the hammer-beams. Each angel holds a shield with the arms of England and France quartered.

Fig. 5 is the detail of the spandrel at *z z*, *Fig.* 2.

Fig. 6 is the spandrel at *r*, *Fig.* 1. The tracery above the collar-beam is shown in *Fig.* 7, and a section of the moulding on the line 3–4, at *Fig.* 9. The section of the great arc on the line 1–2 is given in *Fig.* 8, and a section through the pillar *g* on the line 5–6 in *Fig.* 10.

PLATE XXXIII.—The construction of the conical roof, *Fig.* 1, Nos. 2, 3, 4, 5, and 6, will be evident from the drawings without detailed description. The main principals, it will be seen (No. 3), are united at the top by being inserted into iron sockets cast in one piece; and the frame is completed by struts and an iron tie-rod. The other four principals are framed like a queen-post roof, as shown in *Fig.* 4; and the ties of all the principals are connected at the centre by the radiating straps seen in No. 5, through the central circular part of which the tie-rod No. 6 passes, and is secured by a nut. The same letters refer to the same parts in most of the figures, excepting *a*, which, in Nos. 1 and 2, is the larger circular purlin, but in No. 4 the straining-sill between queen-posts.

Fig. 2.—Nos. 1, 2, 3, and 4 show the construction of a domical roof. The curved ribs are supported by struts from the principals, as seen in Nos. 3 and 4. The plan and elevation exhibit the curved arrises which the sides of the horizontal ribs assume when cut to the curvature of the dome, as at *a*, *Fig.* 2, No. 3.

PLATE XXXIV. *Fig.* 1.—Nos. 1, 2, 3, and 4 show the construction of a domical roof with a circular opening in the centre for a skylight. Two of the main principals, C D and the corresponding one, are framed with a king-post *c*, as shown in No. 3: the others at right angles to these, with queen-posts, as seen in No. 4. The main ribs correspond to the principals, and the shorter ribs are framed against curbs between them, as at *a*, Nos. 1 and 3.

Fig. 2.—Nos. 1, 2, and 3 show the framing of an ogee domical roof on an octagonal plan. The construction will be readily understood by inspection; and the method of finding the arris ribs, shown in No. 3, will be understood from what has already been said when treating of hip-rafters.

PLATE XXXV.—The figures on this plate illustrate the construction of a timber steeple.

Fig. 1 is a horizontal section of the square part of the steeple on the line A A in *Figs.* 2 and 6, and also a plan of part of the roof, showing the four principals which carry the steeple. Each principal carries three main posts *a d a*, forming the carcass of the square part, and the two interior principals carry also the additional posts *b b*, to form the octagonal part above. But the explanation of the horizontal sections will be more easily comprehended in connection with *Fig.* 2, which is a vertical section of the steeple and roof on a line coinciding with the face of the interior principal *a c d c a* in *Fig.* 1.

Fig. 2.—A A are the principal rafters; B B, the tie-beam; C C, queen-posts carried up to form the framing of the square portion of the steeple, and marked *a a* in *Fig.* 1; D, king-post, marked *d* in *Fig.* 1; F, secondary rafters; E E, straining piece; G K H, struts; P, the common rafter; *r*, the purlin; *x*, the gutter-bearer; *y*, the straining-sill; *w u*, a bolt uniting the rafters, tie-beam, and pillow-piece; *g*, a strap uniting the queen-posts, rafter, and straining-piece, and the post L, which is carried up to form the octagonal part, and is marked *b* in *Fig.* 1. The struts H and M serve to discharge the weight of L to the king-post: M is shown on the section *Fig.* 1 at *m m*; and the strut *n*, shown in dotted lines, serves the same office in respect of the outer post of the octagon, and is marked *n n* in *Fig.* 1: N is a counter-brace, the intersection of which with M is marked *c* in *Fig.* 1. The strut *o* supports the cross-piece O at the point where the bearers *h h h*, in *Fig.* 1, rest on it. Horizontal pieces unite the summits of the four king-posts, and are marked *l l* in *Fig.* 1, and *g* in *Fig.* 2. Similar pieces, *k k* in *Fig.* 1, and *g* in *Fig.* 2, unite the summits of the queen-posts, and also the posts forming the octagon at successive stages. The exterior posts of the octagon are supported by the horizontal

bearers shown in dotted lines on *Fig.* 1, and marked *e e e e, f f.* The posts stand on the small parallelograms *g g g g.* At the height of the head-piece Z, the square portion of the steeple terminates, and the octagonal framing is alone continued. *Fig.* 3 is a horizontal section on the line B B, in which *a a a a, b b b b* are the posts standing on the parts *b g* in *Fig.* 1. *Fig.* 4 is a section through C C, in which the same posts are indicated by the same letters; and *Fig.* 5 is a plan of the domical termination of the steeple. The lines D D, E E, and F F in these figures indicate the position of the vertical section *Fig.* 2. The parts of the section *Fig.* 2 above B B will be sufficiently understood by inspection, and need not be described in detail. *Fig.* 6 is an elevation of the steeple. The horizontal lines A A, B B, and C C are the lines of section, *Figs.* 1, 3, and 4.

PLATE XXXV.ª *Fig.* 1.—No. 1 is a sectional elevation, and Nos. 2 and 3 are horizontal sections of the tower of the Town-hall, Milford, Massachusetts, erected from the designs of Mr. Thomas W. Silloway, of Boston, U.S., who has kindly supplied the drawings of this and the following example.

The mode of framing is very simple, and will be understood by inspecting the drawings. *Fig.* 1, No. 2, is a horizontal section or plan at the line A–B in No. 1, immediately above the floor of the first story of the tower. A A, A A, A A, A A are horizontal timbers framed between the principal posts, and strongly strapped and bolted to them, as seen in No. 1: B B, B B are dragon-pieces crossing the angles, to support the posts C C, C C of the upper portion of the tower. Crossing the angles are also angle-braces, and these and the dragon-pieces are securely bolted to the horizontal timbers. No. 3 shows a horizontal section at C–D, wherein the arrangements are of much the same nature as in No. 2. The principal posts carry strong capping-pieces F F, F F, which again carry the dragon-pieces L L, L L, and are also firmly united by the angle-braces O O, O O. The use of the various struts and braces is so obvious as not to require further description.

Fig. 2, No. 1.—In this figure, the principal posts are capped over at the level where the tower diminishes in diameter; and the posts for the octagonal upper portion of the tower are, as in the preceding example, carried by dragon-pieces resting on and bolted to horizontal timbers framed into the principal posts, as seen at No. 2. The arrangement of the horizontal timbers or capping-pieces for the support of the octagonal spire, is shown in No. 3.

PLATE XXXVI.—Spire of La Sainte Chapelle, Paris.

The ancient edifice which this elegant spire surmounts was built in 1248 to contain the relics which St. Louis brought from Palestine. It was erected from the designs of Pierre de Montreuil, the celebrated architect, who built also the castle of Vincennes. The original spire was demolished a short time before the Revolution. It was said to be a marvel of boldness and lightness. The new spire, with the scaffold used in its erection, are figured in the plate; and whatever may have been the merits of its predecessor, this beautiful work may vie with it in the qualities which have been mentioned as its characteristics.

Fig. 1 is a section of a part of the roof and an elevation of the spire.

Fig. 2 is a horizontal section immediately above the roof, and shows also the disposition of the principals which support the spire.

Fig. 3 is the elevation, and *Figs.* 4 and 5 plans of the scaffolding used in the erection of the spire.

Fig. 6.—The upper half of this figure is the half-plan at A B, *Fig.* 1. The lower half is the half plan on the line C D.

Fig. 7.—The upper half of this figure is the half-plan of the base of the spire immediately above the roof; and the lower half is the half-plan on the line E F, *Fig.* 1.

FRAMING—JOINTS—STRAPS.

PLATES XXXVII.—XXXIX.

Carpentry differs from masonry as much in the nature of the materials employed as in the mode of using them. In masonry, stones are usually placed horizontally on their beds, the one above the other,—their weight when they are hewn, and the interposition of some cement when unhewn and amorphous in form, giving them stability. In the constructions of carpentry, on the contrary, a greater or smaller number of long pieces of wood, squared and properly cut, and which may be arranged at any inclination, are combined so that the extremities of one set press on, or are pressed by certain points in the length of the others. Three pieces thus abutting form a compartment in framed work unalterable in form, possessing the qualities of strength and stability, and of rapidity and freedom in construction, which renders this art susceptible of a number of applications to which masonry is not so well adapted.

Thus the carpenter raises with remarkable celerity houses and buildings of all kinds, and divides them into stories in a manner wonderfully simple. He constructs bridges of all spans, and raises and covers vast edifices; and these results he obtains in a manner often preferable to any other kind of construction, and at a much smaller cost.

That elementary form of the timber used in framing which is the most simple, and which the imagination seizes most readily, is the rectangular parallelopipedon. It is also the form which is best adapted to ordinary constructions, and which renders the exact execution of work most easy. In masonry, the same form also favours a simple and commodious arrangement of materials in a stable manner.

That two pieces of wood may meet and abut on each other without the one being caused to turn on its axis by the other, it is necessary that the axes of the two pieces pass through a point common to both. The axes, therefore, of the two pieces should be in the same plane. The axis of a piece of wood, it should be explained, is a right line parallel to its arrises passing through its centre of gravity.

The meeting of two pieces of wood is called the *joint.* The joint is circumscribed by the lines which mark the intersection of the faces of the one piece with the other.

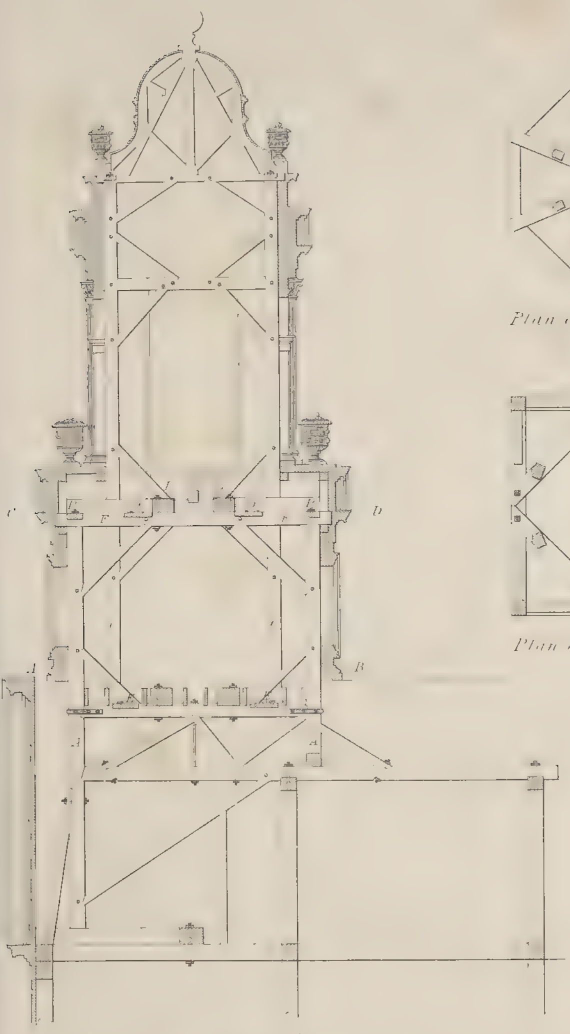
The end of a piece of wood properly cut to be adjusted in contact with another piece is called its *abutment.*

That a joint may be at the same time simple and easy of execution, it is necessary that the bearing faces should be planes of the same size and shape in relation to the planes of the axes. This can only have place when two faces of each piece are perpendicular to the same plane, and the other two faces parallel. This consideration will show, if we have not already said it, that the two pieces of wood must necessarily be square.

TIMBER STEEPLES.

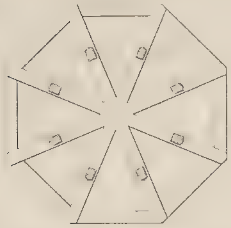
AMERICAN EXAMPLES.

Fig. 1. Nº 1.



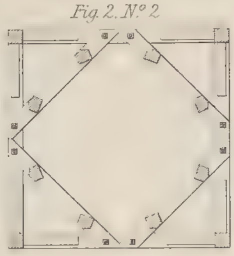
Elevation of Framing of Tower of the Town hall Milford, Mass:

Fig. 2. Nº 3.



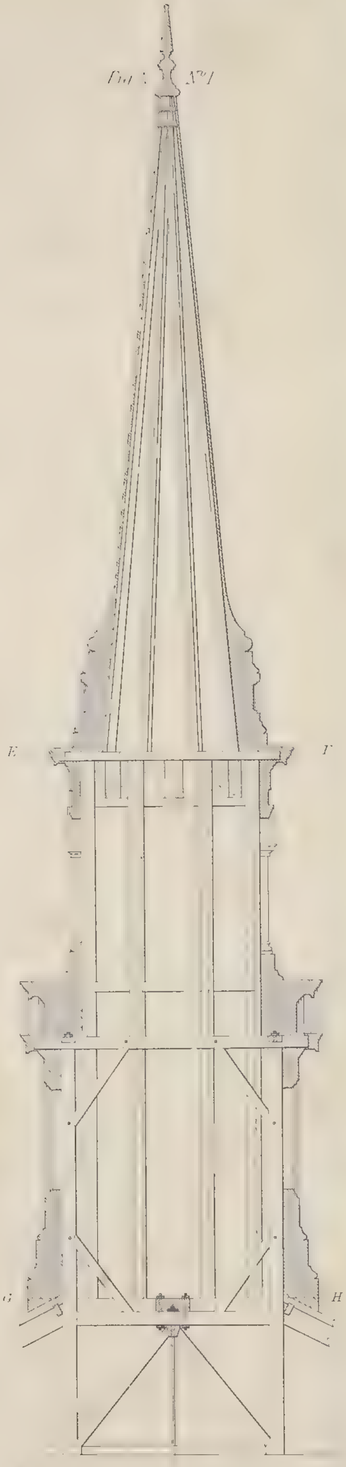
Plan of Spire at E. F

Fig. 2. Nº 2.



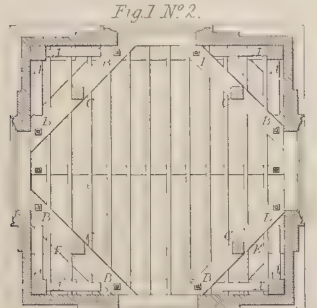
Plan of Spire at G. H

Fig. 3. Nº 1



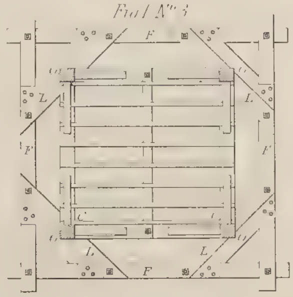
Elevation of Framing of Church Spire

Fig. 1. Nº 2.

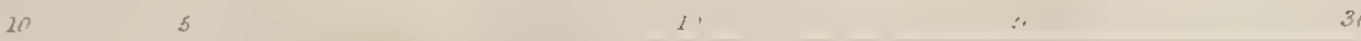


Plan of Tower at A. B.

Fig. 1. Nº 3



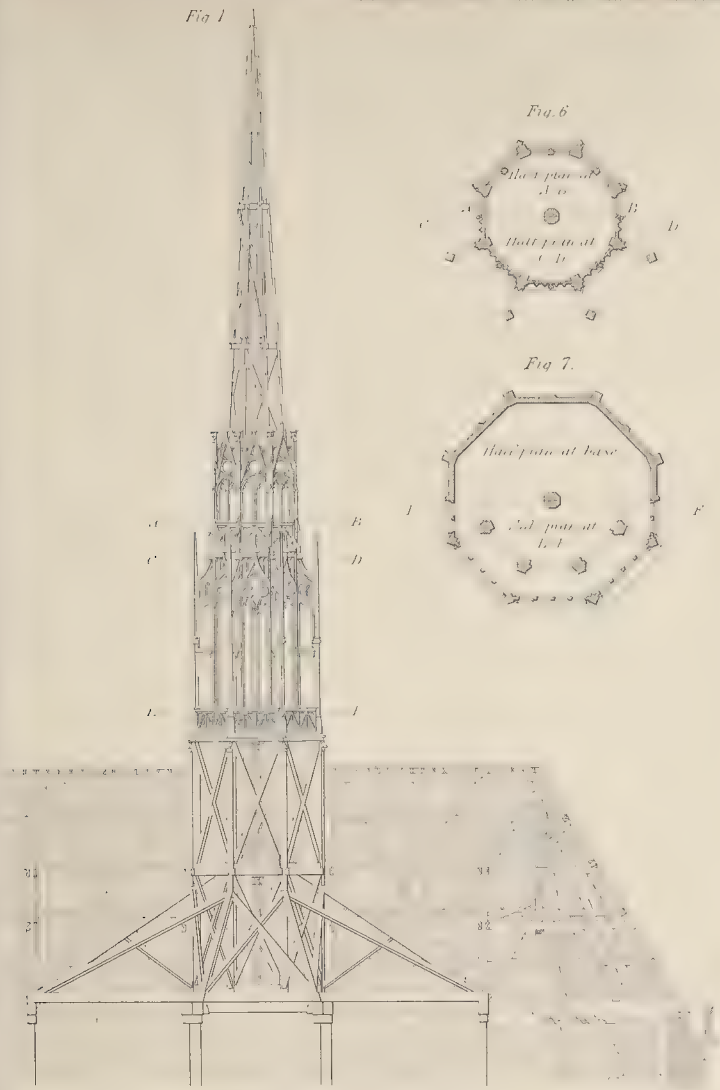
Plan of Tower at C D.



ROOFS.

TIMBER SPIRE AND ROOFING OF LA SAINTE CHAPELLE PARIS

Fig 1



Elevation of Spire and part of Roof.

Fig. 6

Fig 7.

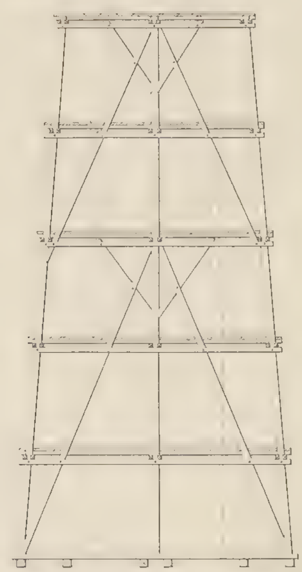
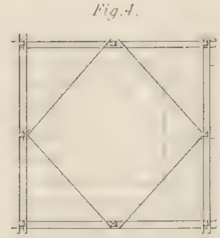
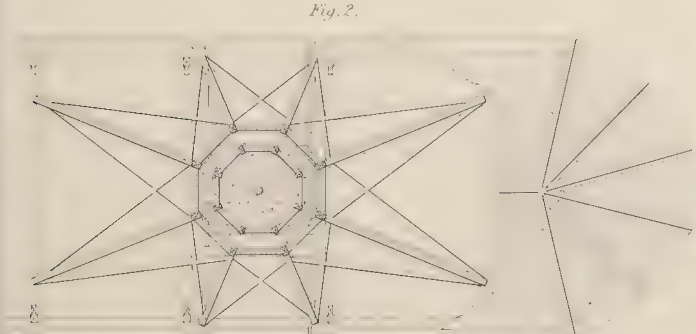


Fig. 4.



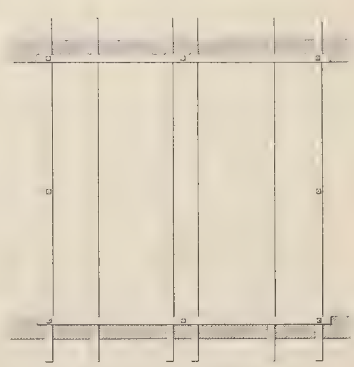
Plan of upper part of Scaffolding

Fig. 2.



Plan of base of Spire, and part of Roof

Fig 5



Plan of base of Scaffolding

Scale for Figs 1 2.3.4.

50 55 60 Feet

Scale for Figs

Feet

A. F. Orridge Del.

BLACKIE & SON, GLASGOW, EDINBURGH & LONDON.

W. A. Beever, Sc

When two pieces of wood are joined by the simple contact of the end of the one piece with its bed on the other, we say that they abut, or are joined by a plain joint. This mode of joining does not prevent the one piece sliding on the other, unless it is fastened with nails or bolts.

The contrivances by means of which one piece is prevented from sliding on the other are called *mortises*, *joggles*, &c.

The putting together of two pieces of wood may be done in three ways:—

1. They may meet and form an angle; and this mode has three cases—

1. The end of one piece may bear upon a point in the length of the other. This case is the most frequent, and gives rise to the mortise-and-tenon joint, the joggle-joint, and to all those which are modifications of these two.

2. The two pieces can be joined mutually by their extremities under any angle whatever. This forms the angle-joint.

3. They may cross each other; and this result is the notch-joint.

II. Two pieces of wood may be joined in a right line by lapping and indenting the meeting ends on each other. This is called *scarfing*.

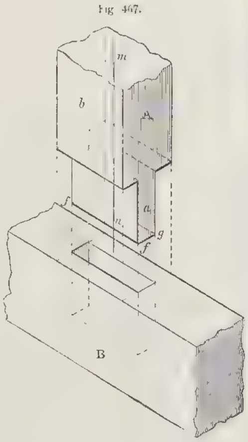
III. Two pieces of wood may be joined longitudinally end to end, the joint being secured by covering it on opposite sides by pieces of wood bolted to both beams. This process is termed *fishing*.

It is requisite to consider the joint as formed by two pieces only, because joints formed by more than two pieces can always be resolved into this.

The mortise-and-tenon joint is the principle of the greatest number of the other joints. It is necessary, therefore, to describe it first at length.

In the simplest case of a tenon-and-mortise joint, the two pieces of wood meet at right angles (Fig. 467). The tenon a is formed at the extremity of the piece A, in the direction of its fibres and parallel to its axis $m\ n$, by two notches, which take from each side a parallelopipedon. The planes of the sides $f\ g$ of the tenon are always parallel to the face b of the timber, and the other planes of the notch at right angles to it.

Fig. 467.



The mortise is hollowed in the face of the piece B, and is of exactly the same size and form as the tenon, which therefore perfectly fills it. The two sides of the mortise which correspond to the breadth of the tenon should be parallel to the direction of the fibres of the wood. The sides of the mortice are called its *cheeks*, and the square parts of the timber A from which the tenon projects, and which rest on the cheeks of the mortise, are called the *shoulders* of the tenon, and its springing from these is called its *root*.

As the cheeks of the mortise and the tenon are exposed to the same amount of strain in a system of framing, it follows that each should be equal to one-third of the thickness of the timbers in which they are made.

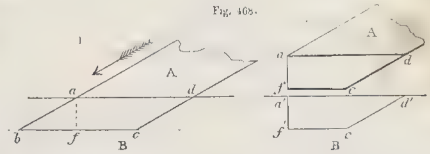
The length of the tenon should be equal to the depth of the mortise, so that its end should press home on the bottom of the mortise when its shoulders bear upon the cheeks; but as perfection in execution is unattainable, the tenon in practice is always made a very little shorter than the depth of the mortise, that its shoulders may come close.

When the mortise-and-tenon joint is cut, adjusted, and put together, the pieces are united by a key or trenail. The key is generally round, with a square head, and in diameter is about equal to a fourth part of the thickness of the tenon. It is generally inserted at the distance of one-third of the length of the tenon from the shoulder.

But a key should never be depended on as a means of securing the joint; for the immobility of a system of framing should result from the balancing of the forces and the precision of the execution. A frame fixed definitely in its place should be stable and solid without the aid of keys, which are to be regarded as mere auxiliaries, useful during its construction.

If the endeavour is made to apply the same manner of forming the mortise and tenon when the timbers are not at right angles, but oblique, several disadvantages arise. Such a joint is represented in the subjoined Fig. 468

Fig. 468.



(No. 1) by $a\ b\ c\ d$. If there were no other inconveniences, the impossibility of inserting the tenon in the mortise when the pieces form a portion of a system, would obviously preclude its adoption, as it would require to be thrust into the mortise in the direction of the arrow; but added to this, there is the difficulty of working the mortise, and the tendency of the thrust of the tenon to rend the piece B in the line $b\ c$.

All these inconveniences are remedied in a very simple manner, by truncating the tenon on the line $a\ f$, as shown in No. 2, by a plane perpendicular to the axis of the mortise-piece B. The execution is thus rendered easy and exact, the evil from the thrust of the tenon is obviated, and the pieces can be put together by dropping the tenon-piece vertically into the mortise.

This is the simplest form of the mortise-and-tenon joint for oblique thrusts. But, obviously the only resistance offered to the sliding of the tenon-piece along the mortise-piece is offered by the strength of the tenon, which is quite insufficient in large carpentry works; and it is therefore necessary to modify the form so as to bring new bearing surfaces into action.

PLATE XXXVII. *Fig.* 1.—No. 1 shows the joint formed by the meeting of a principal rafter and tie-beam, c being the tenon. The cheeks of the mortise are cut down to the line $d\ f$, so that an abutment $e\ d$ is formed of the whole width of the cheeks, in addition to that of the tenon; and the notch so formed is called a *joggle*. No. 2 shows the parts detached and in perspec-

tive. It will be seen that a much larger bearing surface is thus obtained.

Fig. 2.—No. 1 is a geometrical elevation of a joint, differing from the last by having the anterior part of the rafter truncated, and the shoulder of the tenon returned in front. It is represented in perspective in No. 2.

Fig. 3.—Nos. 1 and 2 show the geometrical elevation and perspective representation of an oblique joint, in which a double abutment or joggle is obtained. In all these joints, the abutment, as *d e*, *Fig.* 1, should be perpendicular to the line *d f*; and in execution, the joint should be a little free at *f*, in order that it may not be thrown out at *d* by the settling of the framing. The double abutment is a questionable advantage; it increases the difficulty of execution, and, of course, the evils resulting from bad fitting. It is properly allowable only where the angle of meeting of the timbers is very acute, and the bearing surfaces are consequently very long.

Fig. 4.—Nos. 1 and 2 show a means of obtaining resistance to sliding by inserting the piece *c* in notches formed in the rafter and the tie-beam: *d e* shows the mode of securing the joint by a bolt.

Fig. 5.—Nos. 1 and 2 show a very good form of joint, in which the place of the mortise is supplied by a groove *c* in the rafter, and the place of the tenon by a tongue *d* in the tie-beam. As the parts can be all seen, they can be more accurately fitted, which is an advantage in heavy work. In No. 1 the mode of securing the joint by a strap *a b* and bolts is shown.

Fig. 6.—Nos. 1 and 2 is another mortise joint, secured by a strap *a b* and cotter or wedge *a*.

Fig. 7 shows the several joints which occur in framing the king-post into the tie-beam, and the struts into the king-post. A is the tie-beam; B, the king-post; and C and D, struts. The joint at the bottom of the king-post has merely a short tenon *e* let into a mortice in the tie-beam. The abutment of the strut D is made square to the back of the strut, as far as the width of the king-post admits, and a short tenon *f* is inserted into a mortice in the king-post. The abutment of the joint of C is formed as nearly square to the strut as possible.

The term *king-post*, as has been already stated, gives quite an erroneous notion of its functions, which are those of a suspension tie. Hence the necessity for the long strap *b a* bolted at *d d*, and secured by wedges at *c*, in the manner more distinctly shown by the section, *Fig.* 8, No. 2. The old name *king-piece* is better than king-post.

Fig. 8.—No. 1 shows the equally inappropriately named *queen-post*. A is the tie-beam; B, the post tenoned at *e*; C, the strut; and D, the straining-piece. The strap *b a*, and bolts *d d*.

Fig. 9.—In this figure, the superior construction is shown, in which a king-bolt of iron C D is substituted for the king-post. On the tie-beam A, is bolted by the bolts *a e*, *d f*, the cast-iron plate and sockets *a b c d*, the inner parts of which, *h g*, *h g*, form solid abutments to the ends of the struts B B. The king-bolt passes through a hole in the middle of the cast-iron socket-plate, and is secured below by the nut D. A bottom-plate *e f* prevents the crushing of the fibres by the bolts.

PLATE XXXVIII.—*Figs.* 1 to 5 show various methods of framing the head of the rafters and king-posts by the aid of straps and bolts. *Fig.* 6 shows the heads of the rafters halved and bolted at their junction, and a plate laid over the apex to sustain the bolts which are substituted for the king-post. One bolt necessarily has a link formed in it for the other to pass through.

Fig. 7 shows at D what may be considered the upper part of the same king-bolt as is shown in Plate XXXVII., *Fig.* 9, with the mode of connecting the rafters. A cast-iron socket-piece C receives the tenons *a a* of the rafters A A, and has a hole through it for the bolt, the head of which, *b*, is countersunk. B is the ridge-piece set in a shallow groove in the iron socket-piece. An elevation of the side is given, in which G is the bolt, F the socket-piece, and E the ridge-piece.

Figs. 8, 9, 10, and 11 illustrate the mode of framing together the principal rafter, queen-post, and straining-piece. In the first three examples the joints are secured by straps and bolts; and in the last example the queen-bolt D passes through a cast-iron socket piece C, which receives the ends of the straining-piece and rafter, as those of the two rafters are received in *Fig.* 7.

Figs. 12 and 13 show modes of securing the junction of the collar-beam and rafter by straps; and *Figs.* 14 and 15, modes of securing the junction of the strut and the rafter by straps.

LENGTHENING BEAMS, &c.—In large works in carpentry it is often necessary to join timbers in the direction of their length, in order to procure scantlings of sufficient longitudinal dimensions. When it is necessary to maintain the same depth and width in the lengthened beam, the mode of joining called *scarfing* is employed. Scarfing is performed in a variety of ways, dependent upon whether the lengthened beam is to be subjected to a longitudinal or transverse strain. This method of joining is illustrated in Plate XXXIX., *Figs.* 1 to 13.

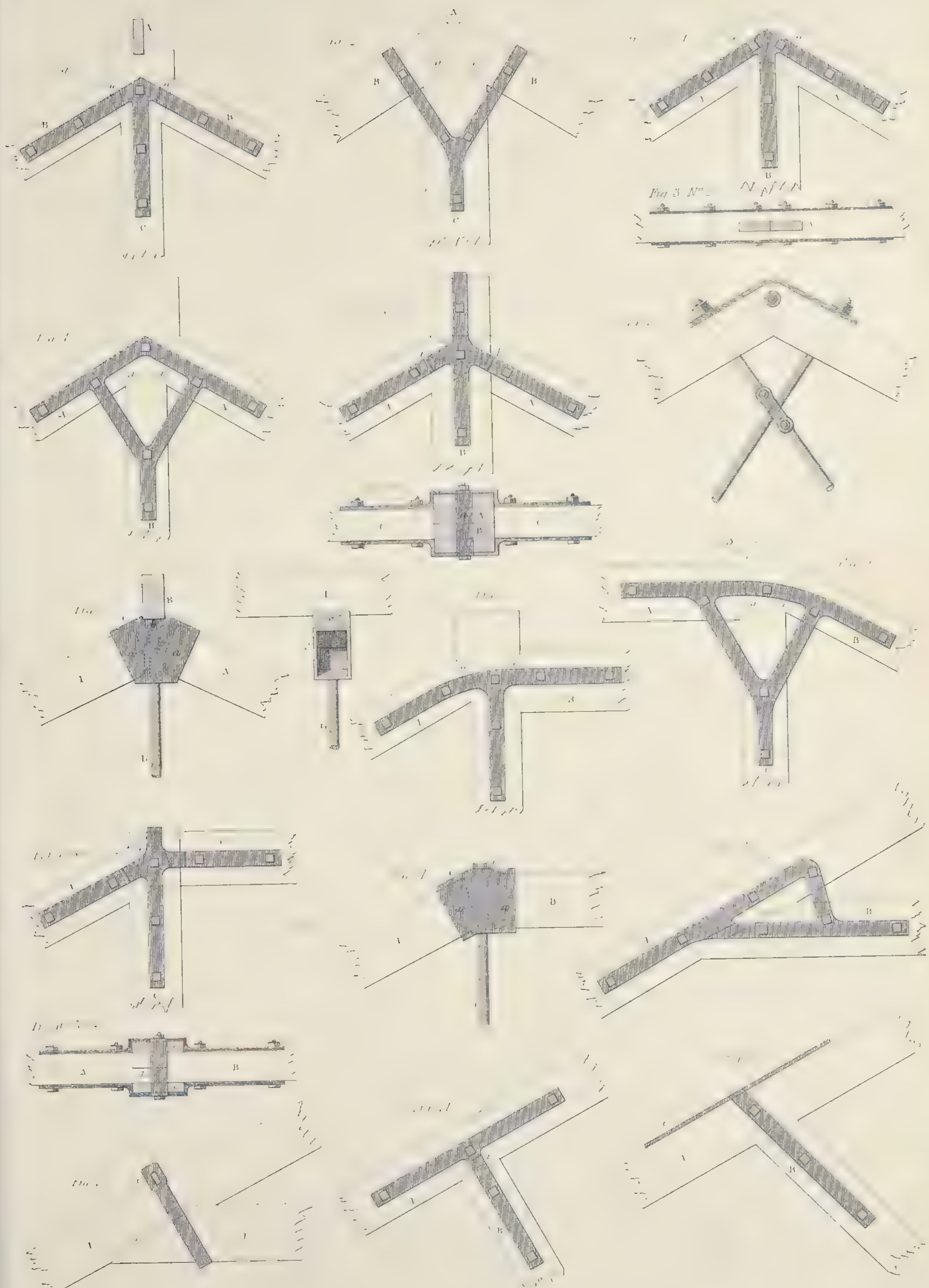
In *Fig.* 1 a part of the thickness of the timber is cut obliquely from the end of each piece, and being lapped over each other, the joint is secured by bolts. In this case the joint depends entirely on the bolts. Iron plates are interposed between the nuts and the timber, to prevent the screwing up of the nuts injuring the beam.

In *Fig.* 2 a key is added in the middle of the joint, notched equally into both beams. In *Fig.* 3 the joint is improved by its surface being indented on each joint, and the key driven between. In this example continuous plates of iron are placed to prevent injury from the bolts. *Figs.* 4, 5, 6, 7, 8, 9 are all variations on the last figure. In *Fig.* 10 the beams are halved together vertically, as shown by the plan No. 2 and section No 3. They are keyed at the centre and secured by iron straps. In *Fig.* 11 the joint is made much larger and halved, the end of each beam is scarfed and keyed, as in *Fig.* 3, and the joint is secured by two straps and seven bolts. No. 1 is the side, and No. 2 the top of the beam.

Figs. 12 and 13 are examples of scarfs formed by the interposition of a third piece *b*.

When the beam does not require to be of the same dimensions throughout, it is sometimes lengthened by the process termed *fishing*. The ends of the beams *a a*, *Fig.* 14, are abutted together, and a piece of timber *b b* is placed on each side, and secured by bolts and keys.

Fig. 15 is an example of a fished beam, in which the fishing-pieces *b b* and timbers *a a* are tabled, and indented, and keyed together.



J W Lowry fc

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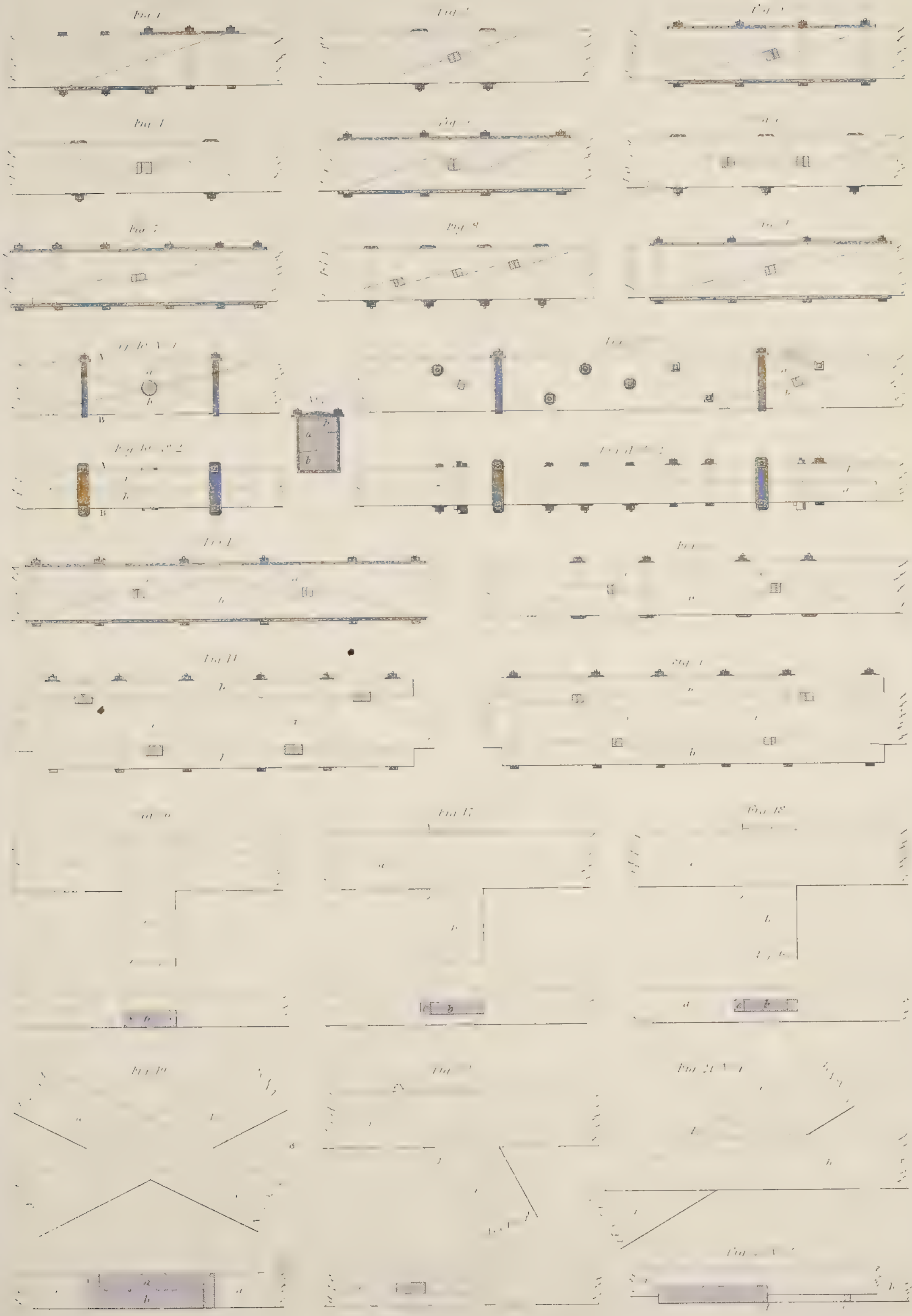
JOINTS.

SCARFING, LENGTHENING BEAMS.



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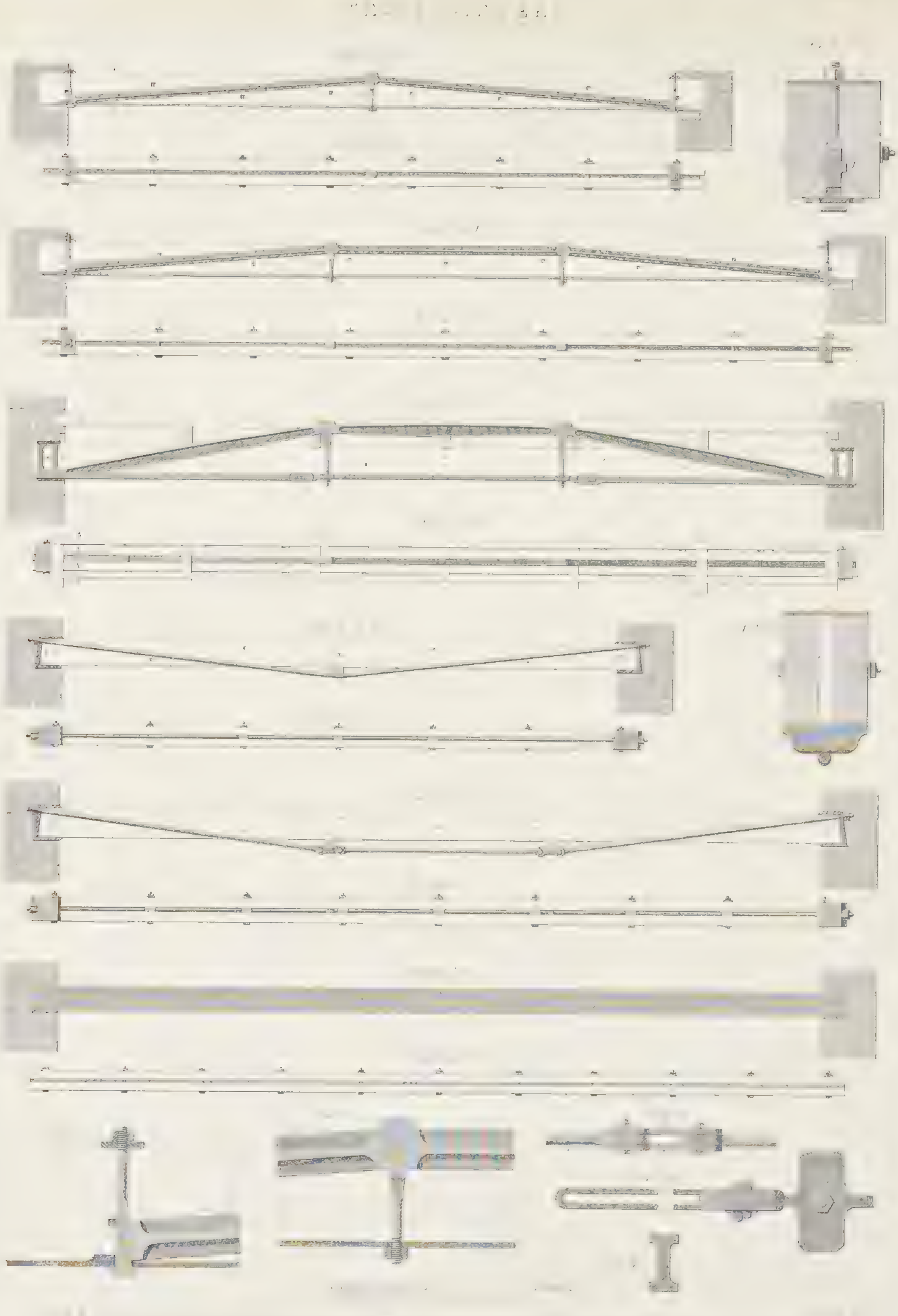
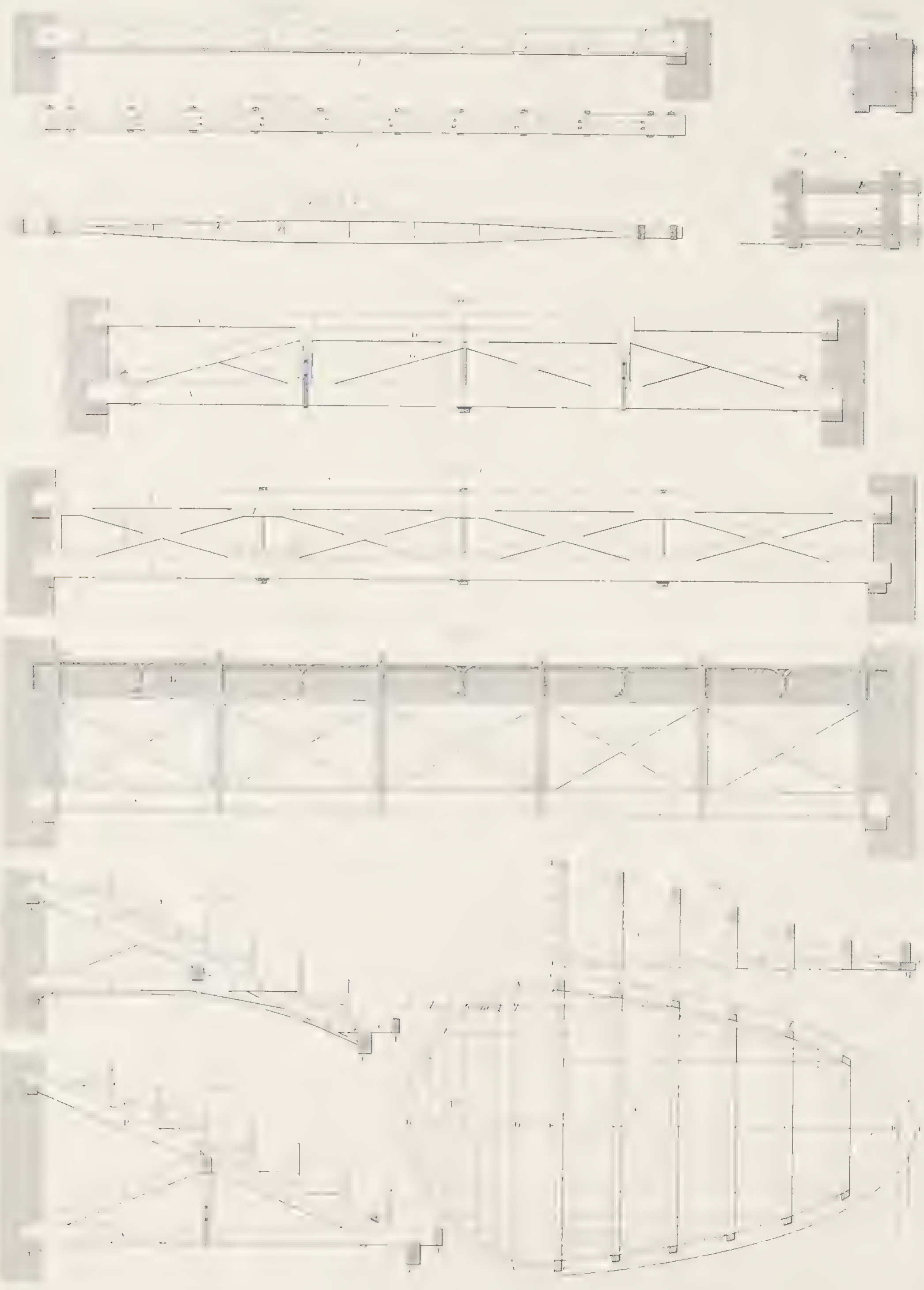
BLACKIE & SON, GLASGOW, EDINBURGH & LONDON.





DOVETAILING, HALVING, &c.—*Fig.* 16 shows two pieces of timber joined together at right angles by a dovetailed notch. As to dovetails in general, it is necessary to remark that they should never be depended upon in carpentry for joints exposed to a strain, as a very small degree of shrinkage will allow the joint to draw considerably.

Figs. 17 and 18 show modes of mortising wherein the tenon has one side dovetailed or notched, and the corresponding side of the mortise also dovetailed or notched. The mortise is made of sufficient width to admit the tenon, and the dovetailed or notched faces are brought in contact by driving home a wedge C. Of these, *Fig.* 18 is the best.

Fig. 19.—Nos. 1 and 2 show the halving of the timbers crossing each other. *Fig.* 20.—Nos. 1 and 2 show a joint similar to those in Nos. 17 and 18, but where the one timber *b* is oblique to the other *a*.

Fig. 21.—Nos. 1 and 2 show the mode of notching a collar-beam tie into the side of a rafter by a dovetailed joint. The general remark as to dovetailed joints applies with especial force to this example.

TRUSSED GIRDERS OR BEAMS.

PLATES XL., XLI.

The general principle of trussing, and the object sought to be gained by its use, have been spoken of in the introduction to the article on roofs.

PLATE XL. *Fig.* 1.—No. 1 is an elevation of a trussed girder, with one of the flitches removed to show the trussing. No. 2 is a plan of the beam, and No. 3 a section through the line *a b*. The trussing-bars C, No. 1, are of iron, and are shown in section enlarged at *d*, No. 3. An iron tension-plate D extends along the bottom of the beam, and connects the abutment bolts A A. These bolts pass between the flitches, and are screwed down upon an iron plate *b*. The central bolt B fulfils the functions of the king-post of a trussed roof. The beam is generally sawn in two, and the ends reversed, when put together in a truss.

Fig. 2.—Nos. 1 and 2 are the plan and elevation of what may be called a queen trussed beam. The construction is the same as the preceding, with the substitution of the queen-bolts B B for the king-bolt.

Fig. 3.—Nos. 1 and 2 show another example of a queen-bolt truss, where greater depth, and consequently greater stability, is obtained for the truss by the use of binding and bridging joists, A being the trussed beam, C the binding joists, and B the bridging joists. The tension-strap is joined together at the points *c c* by cotter-wedges, which have what is technically called a *draw*, so that the driving home of the wedge may bring together the parts

Fig. 4 is an example of a girder trussed with a stirrup-piece B, end-plates A A, and a tension-rod A *b* A. No. 1 is an elevation of the beam; No. 2 is a plan; and No. 3 is an enlarged vertical section through the line *a b*. It is difficult to balance the tensile and compressive resistances in a beam of this kind, so that they may be in action to the same extent and at the same time; and this application of iron in trussing is now considered by many practical men to be nearly useless. The beam is considered to be crippled before the iron begins to be strained, and therefore this mode of trussing is not now in much favour.

Fig. 5.—Nos. 1 and 2 illustrate the application of the tension-rod on what may be considered the queen-post principle, there being two stirrups at *a a*.

Fig. 6.—Nos. 1 and 2 show a combination of timber and wrought-iron. The beam is composed of three flitches, the two outer being of timber, and the central of boiler-plate. The flitches are bolted together. In the elevation it is the iron flitch that is shown.

Fig. 7 is an enlarged drawing of the connection of the trussing-piece *d* with the abutment bolt. The portion shown is the end of the girder, *Fig.* 2; *b*, the cog on the tension-plate notched into the bottom of the beam; *d*, the trussing-piece; *a*, a hole through the beam for the transverse bolt, against which the abutment bolt is pressed; *c*, the cross-plate on the top of the beam, on which the nut is screwed down.

Fig. 8 shows the connection of the trussing-pieces *a b* with the abutment bolt in same girder.

Fig. 9 shows the links which connect the tension-rods of girder, *Fig.* 5.

Fig. 10.—An enlarged drawing of the joints of the tension-rods of girder, *Fig.* 3.

Fig. 11.—A section through *a b* of trussing-piece in *Fig.* 3.

PLATE XLI.—Example from Krafft.

Fig. 1.—Nos. 1, 2, and 3 represent what is usually called a truss, but what is properly a built beam in three flitches. The three flitches are indented, as shown by the plan, No. 2, and the parts are brought home by the keys *c c*. They are then bolted together with tiers of bolts. Krafft remarks that this and similar trusses are only suitable for situations in which they are exposed to tensile strains.

Fig. 2.—Nos. 1 and 2 are representations of a compound beam, a modification by Mr. White of the system of M. Laves, architect to the King of Hanover.

The system of M. Laves has for its object the reducing the weight of frames of carpentry, and economizing the timber which enters into their composition. He effects this by making a saw-cut horizontally along the centre of the piece of timber, and extending nearly to its ends. At the ends of the saw-cut he introduces bolts to prevent its extending further, and then forces the halves asunder in the middle of their length to a distance equal to one or one and a half times the total thickness of the beam by inserting pieces of wood, as shown in the figure.

Several experiments to test his system were made by the inventor and others; also by Messieurs Lasnier and Albony, two skilful carpenters of Paris, assisted by M. Emmery, inspector-general of roads and bridges, and M. Biet, architectural inspector of buildings.

In the experiments of M. Laves, four pieces of pine, each 40 feet long, 9 in. thick, and $7\frac{1}{2}$ in. wide, were taken. Three of the pieces were prepared according to his system, the halves being forced apart to the distances respectively of the half of the thickness of the piece, the thickness of the piece, and one and a half times its thickness. The other beam was used in its natural state for comparison.

Each of the four pieces was loaded with weights, beginning at 100 lbs. and increasing to 1700 lbs.

Their deflections under their loads were as follows:—

The piece in its natural state, ...	$5\frac{1}{2}$ inches.
The first prepared beam, ...	$3\frac{1}{2}$ "
The second " "	$2\frac{1}{2}$ "
The third " "	$1\frac{1}{2}$ "

In the experiment of M. Albony, made in 1840, two pieces of pine were taken from the same tree. Each piece was 51 feet $3\frac{1}{2}$ inches long, $7\frac{8}{10}$ inches thick, and nearly 11 inches deep. The distance between the supports was 49 feet $2\frac{1}{2}$ inches. The saw-kerf in the prepared piece was as thin as could be made, and the two halves were separated $5\frac{8}{10}$ inches, by a piece of timber.

Before commencing to load the beams, the deflection due to their own weight was measured. In the unprepared beam it was found to be rather more than $1\frac{1}{2}$ inch, but in the prepared beam nothing. The beams were loaded with weights very gradually increased until they reached $793\frac{1}{2}$ lbs., when the deflection was—in the unprepared beam $19\frac{1}{10}$ inches, and in the prepared beam $2\frac{6}{10}$ inches. Under this load the pieces broke.

M. Lasnier's experiment was made with two beams of very dry pine, each $19\frac{7}{10}$ by $3\frac{1}{2}$ inches, and the distance between the supports was 41 feet 10 inches. The halves were forced asunder $9\frac{1}{2}$ inches.

The beams were loaded by weights of 272 lbs., applied successively, and distributed at three points of suspension. When the load reached $272 \times 3 = 816$ lbs. the prepared beam was deflected $2\frac{1}{10}$ inches, and then, after sustaining it a few minutes, it broke. The unprepared beam broke before the weight reached 800 lbs.

M. Emy, who records these experiments, says—"It does not appear that the strength of a beam prepared according to the system of M. Laves much exceeds that of a beam in its natural state; but its stiffness is much augmented; which may render the preparation useful in several cases."

The beam represented in *Fig.* 2, No. 1, has been sawn in two horizontally, the two pieces again put together, secured by the bolts and straps drawn to a larger scale in No. 2, and then the two halves forced apart by the pieces *b b* inserted between them.

M. Laves applied beams prepared on his system in the construction of floors, roofs, and bridges.

Fig. 3 is a truss on the principle of the queen-post roof: A is the tie-beam, C one of the principal braces, E one of the queen-posts, D the straining-piece, and E and G are struts.

Fig. 4 is a truss formed by the beams A B, straining-pieces *b b*, and braces and counter-braces *d d*. When the braces, straining-pieces, and punchions C are inserted, the whole frame is made rigid by screwing the nuts of the three bolts.

Fig. 5 is a combination of iron and timber. B is a cast-iron beam, and A a timber beam: on the top of the latter is the tension-rod *d*, and on the upper side of this, and under side of the iron beam, are sockets formed for the punchions *f* and braces and counter-braces *e e*. Wrought iron straps embrace the framing at each punchion, and are tightened by cotters at *c c*.

Fig. 6 is the trussed framing for the gallery of a church, where the ceiling underneath is curved. The principal B is notched on the wall-plate G, and also on the beam E: the tie A is secured on the wall-plate H, and bolted to the principal. F is a beam serving the office of a purlin, to carry the gallery joists; D is a strut; *b b* are the floors of the pews; and *c c c* the partitions. C is a hammer-piece resting on the beam E, and bolted to the principal B: its outer extremity carries the piece I, which supports the gallery front.

Fig. 7 is another example of the trussed frame for a gallery. Here a framed principal A D C E, resting on the wall-plate H, and front beam E, supports the beam K, which carries the gallery joists B: *a a* and *b b* are the floors and partitions of the pews.

Fig. 8, Nos. 1, 2, and 3, shows the curb and ribs of a circular opening C B A, No. 2, cutting in on a sloping ceiling: as, for example, a circular-headed window occurring between two principals, such as that shown in *Fig.* 7. No. 1 is a section through the centre B D, No. 2, and E F I, No. 3. The height L K is divided into equal parts in *e f g h i*, and the same heights are transferred to the main rib in A 1 2 3 4 5 B. Through the points A 1 2 3 4 5, in No. 2, lines are drawn parallel to the axis B E I; and through the points *e f g h i* in No. 1, lines are drawn parallel to the slope K H. The places of the ribs 1 2 3 4 5 in the latter, and their site on the plan No. 3, and also the curve of the curb, are found by intersecting lines in the manner the student is already acquainted with.

FLOORS.

PLATES XLII.—XLIV.

Floors are the horizontal partitions which divide a building vertically into stages or stories.

The timbers which enter into the composition of floors are bridging-joists, binding-joists, girders, ceiling joists, and the boards which form the platform. All these, except the last-mentioned, are comprehended under the term "naked flooring," and are strictly within the province of the carpenter.

When the bearing between the points of support is not great, bridging-joists alone are used to support the flooring-boards, and, it may be, ceiling-joists. They are laid across the opening or void, and rest on the wall at each end. A piece of timber, called a wall-plate, is interposed between the ends of the joists and the wall, to equalize their bearing.

A floor of bridging-joists, called a single joisted floor, is the strongest that can be made with a given quantity of timber; but when the bearing is long, the joists, from their elasticity, bend under a moving weight, and thus disturb the ceiling below. When, therefore, the bearing is of such length as to cause the joists to bend, their elasticity is considerably diminished by placing underneath them stronger timbers, called binding-joists. This construction is called a double floor. When it is calculated that the bearing will exceed the limit of strength of the binding-joists, a third mode of construction is adopted, in which larger timbers, called girders, are introduced to support the binding-joists. This construction is called a framed floor. These three kinds of construction shall now be described and illustrated in order.

PLATE XLII. *Fig.* 1. *Bridging-joist or Single-joisted Floors.*—No. 1 is the plan of an apartment: *a a a a* are the walls, *b b* the wall plates, *c c c c*, &c., the bridging-joists, *d d* part of the flooring-boards. The bridging-joists are usually placed from 10 to 12 inches apart: their scantling is dependent on their length, their distance apart, and the weight they have to carry. Rules for calculating their size from these data will be found in the sequel.

No. 2 shows a section through the joists at right angles

FLOORS.

Fig 1. No. 1

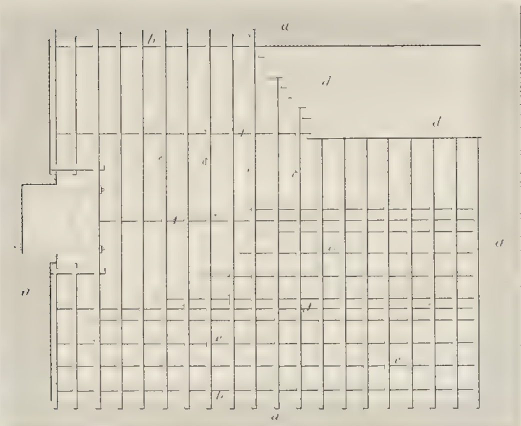


Fig 2. No. 1

Fig 1. No. 2

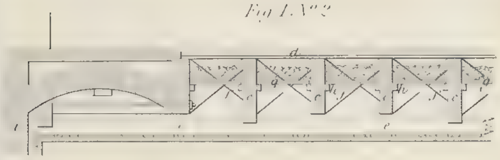


Fig 2. No. 2

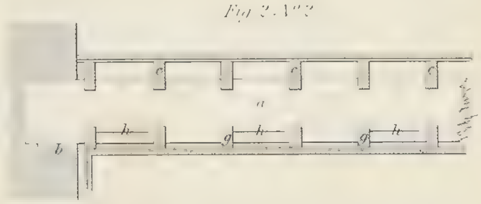


Fig 3. No. 1

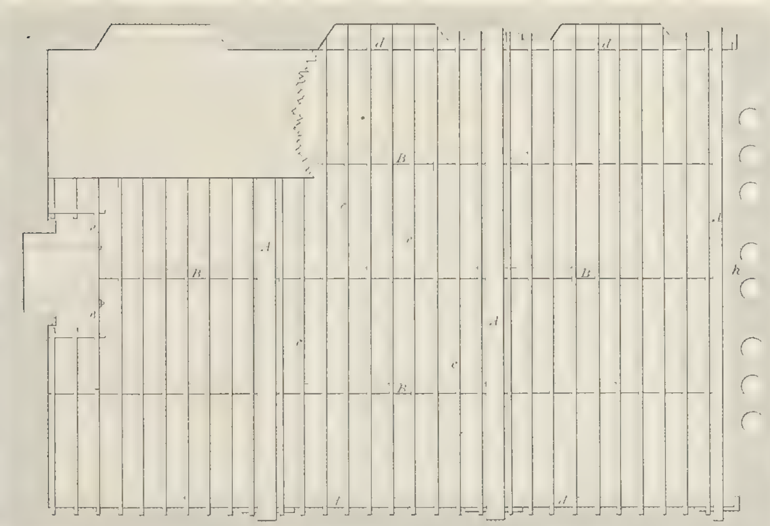


Fig 2. No. 3

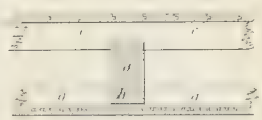


Fig 3. No. 4

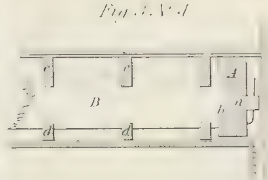


Fig 3. No. 2

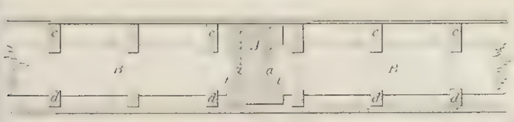
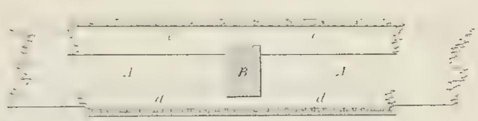


Fig 1. No. 3



Scale to Figs 1, 2 & 3

60 Feet

Scale to details

to their direction: *c c* are the bridging-joists, *d* the edge of one of the flooring-boards, *e e* the side of a ceiling-joist. The ceiling-joists cross the bridging-joists at right angles, as seen at *e e e*, No. 1, and are notched up to them and fastened with nails. Sometimes every third or fourth bridging-joist is made deeper than its fellows, and the ceiling-joists are then fixed to them only. This has the advantages of preventing sound passing so readily, and making the ceiling stand better.

When the bearing of single joists exceeds 8 feet, they should be strutted between, to prevent their twisting, and to give them stiffness. When the bearing exceeds 12 feet, two rows of struts are necessary; and so on, adding a row of struts for every increase of 4 feet in the bearing.

There are three modes of strutting employed. The first and most simple is to insert a piece of board, nearly of the depth of the joists, between every two joists, so as to form a continuous line across. The struts should fit rather tightly, and are simply nailed to keep them in position. The second mode is to mortise a line of stout pieces into the joists in a continuous line across, but the mortises materially weaken the joists. The third mode is represented in the section, No. 2: *f f* are double struts, of pieces from 3 to 4 inches wide, and $1\frac{1}{2}$ inch thick, crossing each other, and nailed at the crossing to each other, and at their ends to the joists. The struts should be cut at their ends to the bevel proper for their inclination. To save the trouble of boring holes for the nails, two slight cuts are made at each end with a wide-set saw, and the strut is nailed through these with clasp-nails. Of the three modes, the last is the best. In No. 1, *f f f* show three lines of struts.

When some joists would, from their position, run into a fire-place or flues in a wall, it is improper to give them a bearing there. In the case of the floor, *Fig.* 1, two short timbers, called "trimmers," are introduced—one on each side of the place to be cleared, with one end resting in the wall, and the other framed into the third joist from it: into the outer side of these, respectively, the end portions of the two first joists are framed, the intermediate portion being dispensed with. The joist into which the trimmers are framed is called the "trimming-joist," and is made thicker than the others, according to the number of joists dependent on it for support. The hearth rests on a brick arch turned between trimmer and wall. Trimming is also resorted to for stair and other openings.

In order to effectually prevent the passage of sound from one story to another, a second floor, of rough boarding, is sometimes inserted between the joists, and covered with some non-conductor of sound,—the usual composition, which is called in England *pugging*, and in Scotland *deafening*, being a mixture of lime mortar, earth, and the light ashes from a smithy. This sound-boarding, or deafening-boarding, as the secondary floor is called, is supported on fillets nailed to the sides of the joists. It is shown in the section, *Fig.* 1, No. 2, where *g g* is the boarding, and *h h* the fillets. Along the joist next the wall a fillet is nailed, so as to fill up the space between the joist and the wall, and admit of the pugging being used there to effectually stop communication.

Fig. 2. *Double Floor, or Floor with Binding-joists.*—No. 1, is a plan of this kind of floor: *a a* are the binding-joists, having their ends resting in the walls, but with templates *b b*, which are short pieces of timber or stone, interposed to lengthen their bearing; *c c* are the bridging-joists, *d d* the wall-plates, *e e* is a trimmer opposite the fire-place, and *f* part of the flooring.

The section, No. 2, shows the connection of the parts; *a* one of the binding-joists, *c c* the bridging-joists, notched over the binding-joist, and *g g* the ceiling-joists under it. Where the saving of depth in the framing is an object, the ceiling-joists are framed into the binding-joists by a chase-mortise, as at *h* in the same figure. No. 3 is a section of the same floor parallel to the direction of the bridging and ceiling joists. The same letters of reference apply to the same parts in both figures.

Fig. 3. *Framed Floor;* the third mode of construction.—No. 1 represents the plan: A A are the girders, with their ends bearing on templates in the walls; B B B are the binding-joists, and *c c* the bridging-joists; *d d* the wall-plates; *e e* the trimmer at fire-place. As the wall *h* contains flues along nearly all its length, the binding-joists do not rest in it, but are framed into an additional girder A. In this case, the tenon passes through the mortise, and is keyed on the other side, as shown in section in No. 4, in which A is the wall-girder, and B the binding-joist.

No. 2 is a section through the girder, showing the manner of framing the binding-joists into it; A the girder, B B the binding-joists, *c c* the bridging-joists, *d d* the ceiling-joists. No. 3 is a section through the floor at right angles to the last section: in it the same letters refer to the same parts.

In framing the binding-joists into the girders, it is necessary to effect a compromise between two evils; for the tenon is stronger the nearer it is to the lower side of the joist or binder on which it is formed, and the mortise weakens the beam or girder the least when it is near the upper side thereof; that is, when it is above the neutral axis. A contrivance, therefore, called a "tusk tenon," is used, which is seen in the sections Nos. 2 and 4. The tenon *a* is a little above the middle of the joist; but its efficiency is increased by the tusk *b*, which relieves it of its bearing, and the shoulder above the tenon is cut back obliquely; and thus, without unduly weakening the girder, a great depth of bearing is obtained for the joist. It is necessary to take great care in fitting the bearing parts to the corresponding parts of the mortise. The tenon *a* should be equal to one-sixth of the depth of the girder; and, according to the best practice, it should be inserted at one-third the depth of the girder from the lower side.

It is a good practice to saw girders down the middle, and to reverse the ends and bolt the halves together with the sawn side outwards, with slips between to admit a circulation of air. By this means the heart of the timber can be examined, and the beam be rejected if unsound: the timber being reduced to a smaller scantling also dries more readily, and is rendered less liable to decay; and as the butt and top of a tree are rarely of the same strength, the girder must be improved by the process, which tends to equalize its strength throughout.

When the bearing of a girder exceeds 22 feet, it is often difficult to get timber of a sufficient size. In this case the process of trussing the girder is resorted to. Various modes of trussing are figured in Plates XL. and XLI., and described in p. 149.

Variations in the Modes of Constructing Floors.—In framed floors, especially in Scotland, binders are

frequently omitted, the girders are more numerous, and the bridging-joists are either notched down on them if the space will admit, or tenoned into them if otherwise. The ceiling joists, too, in place of being notched or tenoned, are suspended to the bridging-joists by small straps of wood. Thus, the separation between the floor and the ceiling is more complete, and sound is less readily transmitted.

PLATE XLIII. *Fig.* 1 is the plan, *Fig.* 2 a transverse section across the direction of the girders, and *Fig.* 3 a longitudinal section, at right angles to the last, of such a floor. The same letters refer to the same parts in all three figures.

a a, girder; *b b*, bridging-joists dovetailed into the girders; *c c*, ceiling-joists hung to the bridging joists by the straps *d d*; *e e*, fillets for the support of the sound-boarding or deafening-boards, nailed to the sides of the bridging-joists; *f f*, sound-boarding lying loosely on the fillets *e e*; *g g*, flooring-boards grooved and tongued; *h h*, ceiling-laths; *m m*, plaster ceiling; *n n*, pugging or deafening, composed generally of lime, earth, and forge ashes in equal proportions.

Fig. 4 is the plan, and *Fig.* 5 a section of part of a warehouse floor composed of girders *a a a*, supported by cast-iron columns *b b b*, and supporting the floor of planks *c c c*.

Figs. 6 and 7 are plan and section of part of a warehouse floor composed of trussed girders *a a*, supported on iron columns *b b*, bridging-joists *c c*, and flooring-boards *d d*. *Fig.* 8 is a vertical section through the floor at right angles to that shown in *Fig.* 7; and *Figs.* 9 and 10 are plan and section of the head of the cast-iron pillar, drawn to double the scale.

PLATE XLIV. *French Floors.*—*Fig.* 1 is the plan of a portion of a floor composed of joists sustaining flooring boards; and various modes of disposing the latter are shown.

Fig. 2 is a longitudinal section on the line A B of *Fig.* 1; and *Fig.* 3 a transverse section on the line C D of the same figure. *Fig.* 4 is a transverse section on the broken line E F.

a a are the joists on which the flooring-boards are nailed; *b b* boards, the full width of the deals or other timber out of which they are cut: these are gauged to a width, and jointed together by a groove-and-tongue joint: they are generally 1 inch to 1¼ inch thick, according as the joists are nearer or further apart. Each board is attached to each joist by two or three nails, according to its width; and when all the boards are laid and nailed, the joints are dressed off with a plane.

c c shows the floor composed of narrow deals, jointed with groove and tongue, and each deal fastened by two nails to each joist. When the flooring-boards are of narrow deal, they are generally planed on both sides, to reduce them to uniform thickness; and in this case the upper surface of each joist is also planed, and all the joists are carefully adjusted in the same perfectly level plane. The end joints of the boards are arranged so that the joints of two contiguous boards shall never fall on the same joist; and care is taken, for the sake of appearance, to make the joints of alternate boards fall on the same straight line across the apartment, and at the middle of the length of the intermediate boards. But when it is possible to obtain boards the whole length of the apartment, the preference is given to a floor without end joints. The end joints of the boards are, in many cases, made also with groove-and-tongue; but as the joints occur only on the middle of a joist, and can be well nailed, it is by many considered superfluous.

To render a floor still more solid, and prevent the passage of sound, a second course of boarding is laid above the first, with a space between. This is shown on the extreme right in *Fig.* 1. *f f* are fillets nailed on the first laid boarding, conformably with the joists; *g g* are the boards of the second floor; and to *deafen* the floor, the intervals between the fillets are filled with lime-mortar, or with lime and ashes, or with dry moss.

When lime-mortar is used, the upper boarding must be laid before it is quite dry, lest the hammering required in fixing it should break up the deafening. When dry moss is used, it is driven in as the upper boards are laid, and rammed hard. The second floor-boards do not require their joints to be grooved and tongued, as the penetration of dust, &c., is prevented by the grooving and tongueing of the first floor.

h h shows another method of laying the flooring-boards, where the joints meet in a straight line on a joist; and *i i* shows the manner of laying, called in this country *herring-boning*. In either of these two last methods, the width of the board should not be less than a twelfth, nor more than a sixth of its length; and the best mode of jointing is by grooving and tongueing.

Where it is customary to wash floors with water, M. Emy considers a plain joint preferable to a groove-and-tongue joint for the boarding; for when the board grows old, the surface rots or decays, and the edge of the board, in the case of the groove-and-tongue joint, having little solidity, the fibres splinter off.

In nailing the boards in common floors, what are called floor-nails are used. These have the shank square in section, the head large and round, and its top shaped like a very flat diamond point. For better work, nails called *pointes de Paris* are used. The shank of this kind of nail is cylindrical, and the head small, so that it may be driven under the surface of the board by a punch. But still better are the *clous a parquet*, which correspond to the English flooring-brads.

Sometimes, too, screws are used; in which case the upper surface of the boards is countersunk by a cylindrical hole, so as to receive entirely the head of the nail, and admit of the surface of the floor being planed off. The cylindrical holes are filled in with pieces of wood of the same kind as the boards, with their fibres in the same direction, and strongly glued, and driven in with a mallet. This method is used chiefly for oaken floors.

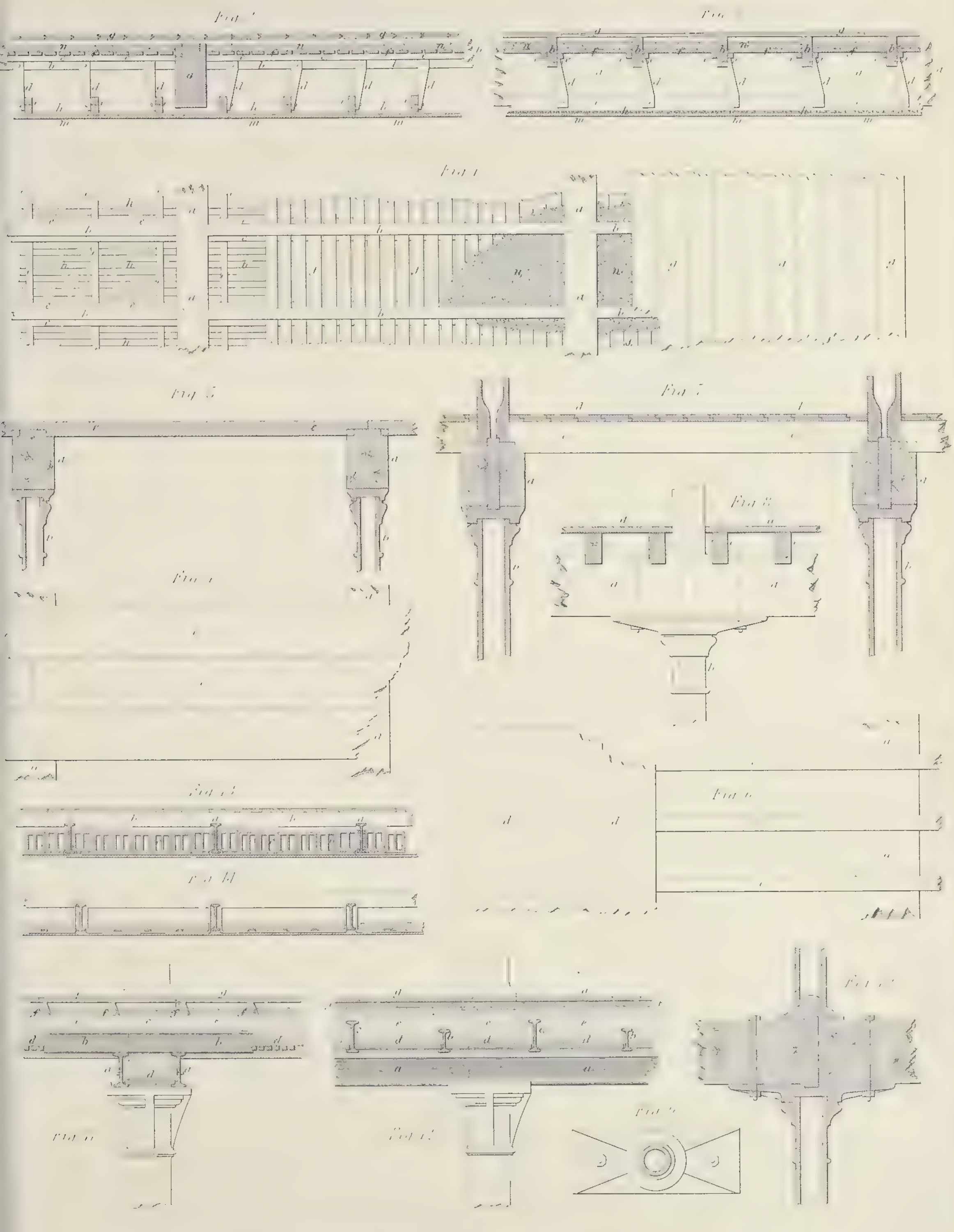
As it is not usual in France to cover the floors with carpets, more attention is paid to the appearance of their surface than with us. Sometimes, boards of different kinds of wood are used, and combined so as to produce contrast in colour, and in the direction of the fibres; and even with one kind of wood agreeable combinations are produced by merely contrasting the latter.

Floors of parquetry are not here touched upon, as belonging, in France, more to the cabinet-maker than the carpenter and joiner.

The flooring-boards cover only the upper surfaces of the joists. Sometimes their other three faces are left

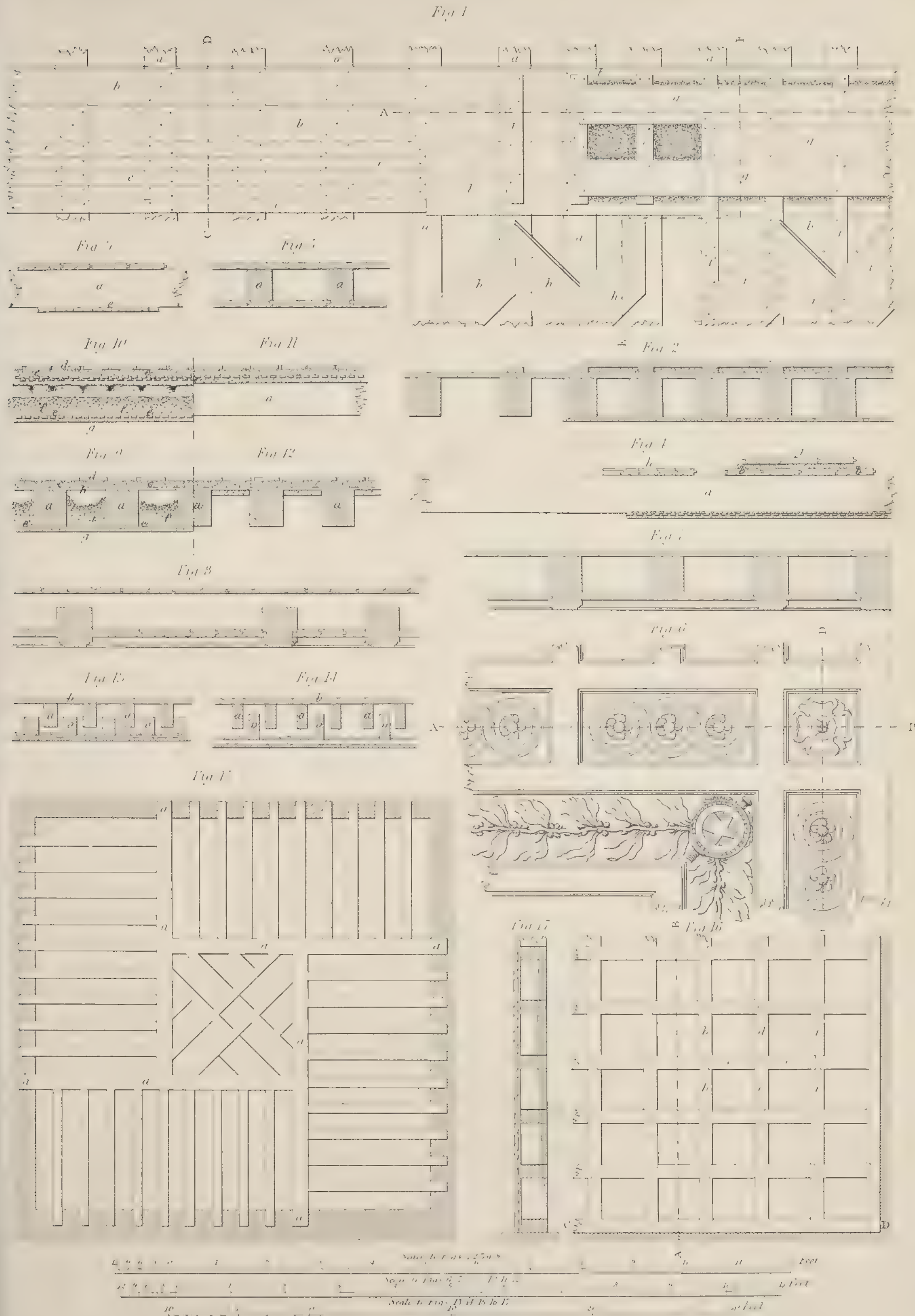
FLOORS.

WAREHOUSE FLOORS, FIRE-PROOF FLOORS &c.



FLOORS.

FRENCH FLOORS AND FLOORS CONSTRUCTED OF SHORT TIMBERS



W. J. Bassett

visible; but more often their under side is covered to form a ceiling to the apartment below.

At *e*, *Fig.* 3 is a section of the platfond or ceiling, composed of thin planks, jointed longitudinally with a groove-and-tongue joint, and nailed on the under side of the joists. The deal used for this purpose being preferably lime-tree, which in French is called *tilleul*, the covering itself came to be called *tillis*.

The joints of the platfond boards are sometimes beaded, and the whole platfond is generally painted like the rest of the wood-work of the apartment.

Sometimes the platfond boarding does not stretch across the under side of the joists, but is framed in between them, as in *Fig.* 5, which is a section perpendicular to the direction of the joists *a a*. When the fibres of the boards are perpendicular to the direction of the joists, the work is more solid. When the platfond boarding is flush with the under side of the joist, as in *Fig.* 5, the tongue has to be worked on the upper edge of the board, in which case any shrinkage of the timber makes a visible opening; but when the boarding is a little recessed, as in *Figs.* 7 and 8, the tongue can be made on the under side, and the shrinkage is not observed.

The platfonds are frequently decorated by being divided into compartments by the joists, and these compartments are enriched with paintings and sculptures. This sort of platfond is much in use where plaster is not easily obtained. In *Figs.* 6, 7, and 8 is represented a platfond of this kind. *Fig.* 6 is a plan of the ceiling looking up. *Fig.* 7 is a section of the floor by a vertical plane passing through A B in *Fig.* 6, and *Fig.* 8 another vertical section by a plane perpendicular to the former on the line C D. In these are shown the joists, the boarding of the floor, and the cross pieces framed between the joists with mortise and tenon, to form the compartments. In *Fig.* 7, the platfond boards are cut in the direction of their fibres, which is perpendicular to the fibres of the joists, and in *Fig.* 8 they are cut across the direction of their fibres. If such a platfond were ornamented by painting, the shrinkage of the wood would obviously mar the work by making the joints visible; the practice is therefore to prepare frames to fit the panels or compartments, and on these to stretch cloth, on which the ornamental painting is made.

At Paris, and in other places where plaster is abundant, flooring of stone or tile is often substituted for the timber floor. This mode of construction is shown in *Figs.* 9 and 10—*Fig.* 9 being a section on a line crossing the direction of the joists, and *Fig.* 10 a section passing through the middle of the interval between two joists; *a a* the joists, *b b* laths of oak crossing the joists and nailed to them, *c c* composition of plaster on which the stones or tiles are laid, *d d* the stone or tile floor, *e e* laths to support the ceiling, *f pugging* or *deafening* between the joists, *g* plaster ceiling united to the deafening through the interstices between the laths.

The pugging, *f*, not only prevents the passage of sound, but also of disagreeable odours. It is therefore especially used over kitchens and stables.

The pugging is formed of a coarse mortar, composed of lime and pieces of stone or of old plaster. It is from 3 to 4 inches thick at the middle of the interval between the joists, but at the sides it is carried up to the under side of the laths which support the floor, thus forming a sort of trough; and to make it better adhere to the wood, the sides of the joists are studded with nails or wooden pins.

When this extent of pugging is not required, the under side of the floor laths merely is plastered, as seen in the sections, *Figs.* 11 and 12.

In floors of great span, the elasticity of the joists would break the plaster ceilings attached to them. To prevent this, one series of joists is used to carry the floor, and another series of slenderer joists to carry the ceiling. A vertical section of this arrangement is shown in *Fig.* 13, in which *a a* are the flooring joists, *b b* the flooring boards, and *o o* the ceiling joists. When strong split laths of oak are used, the ceiling joists are placed farther apart, as in *Fig.* 14, in which *a a* are the floor joists, *b b* the flooring boards, and *o o* the ceiling joists.

Combination of timbers of small scantling to form floors of large span without intermediate support.

The first variety of such floors to be described is that invented by Sebastien Serlio, a celebrated architect, who was born in Bologna in 1518, and died at Paris in 1552.

On the principle of construction adopted by Serlio, the principal timbers form great rectangular divisions, each timber having one end supported by the wall and its other end supported by the adjacent timber.

Four great joists, *a d a a* (*Fig.* 15), have each one of their ends *a′ a′ a′ a′*, resting in the wall of a square apartment, and they are arranged perpendicularly to each other, so that the outer end of each beam is supported by the middle of the next adjoining.

This principle will be familiar to most of our readers from the amusing illustration of it shown in books of philosophical recreations, which consists in placing three or four knives resting on the ends of their handles and interlacing their blades by crossing them alternately, by which means a considerable weight may be supported at the meeting of their points.

The spaces between the main joists and the walls are filled in with ordinary joists resting in the wall and framed into the main joists, which serve as trimmers, and the central square is filled in also with joists placed diagonally, so that the weight may be borne equally by the four main joists.

Fig. 16 is the plan of part of a floor of the Palace in the Wood, at the Hague. It is an extension of the system of Serlio. The hall, of which this is the floor, is 60 feet on the side; and the figure represents one of the four angles. The floor is constructed of small girders of oak, forming 300 square panels. Any one of the girders, such for example as *c*, is tenoned at each end into two other girders, as *b* and *f*, and carries the ends of other two girders *e* and *d*, which are tenoned into it at the middle of its length. Those girders which run on the walls are tenoned into wall-plates C D, imbedded in, and fixed to the masonry.

The floor is composed of a double thickness of boards, crossing each other at right angles, grooved and tongued, and nailed to the girders. *Fig.* 17 is a section on the line A B on the plan, showing the two thicknesses of boards.

The girders are cut below so as to form a slightly concave surface, with the object of compensating for any sagging; which would have had a disagreeable effect. The result, also, is to diminish the weight at the centre of the floor. In constructing this kind of floor, the sides should

be divided into an unequal number of spaces, that there may be a square compartment in the centre.

Fire-proof Floors.—Of late, much attention has been given in this country, and still more in France, to the construction of fire-proof floors. In Plate XLIII., illustrations are given of both the English and the French methods of construction. *Figs.* 11 and 12 are longitudinal and transverse sections of Messrs. Fox and Barrett's system. *a a* are the main girders, consisting of a pair of rolled joists; *b b*, *c c*, the ordinary joists, which are alternately 6 inches and $4\frac{1}{2}$ inches deep; *d d*, wooden battens, about 1 inch square, resting on the bottom flanges of the ordinary joists and main girders, and placed like laths with a narrow space between them. On the top of these is spread a layer of coarse mortar, which being pressed down between the battens, forms a good surface of attachment for the ceiling. The space between the main girders and the spaces between the joists are then filled in with concrete, *e e*, in which are imbedded small quarterings or joists, *f f*, to which the flooring-boards are nailed. The concrete sets and consolidates the whole floor into one slab.

Fig. 13 is a French fire-proof floor on the system of Thrasné. It consists of rolled double-flanged girders, supporting common bridging joists of timber, *b b*, which support the flooring-boards. The iron girders are connected together by transverse tie-rods bent round the lower flanges. These support hollow bricks, *c c*, which are cemented together with plaster of Paris.

In *Fig.* 14 is a section of a lighter floor. The girders are connected by light iron ties bent over them; and with these ties are interlaced cross bars of light iron, so as to form together a complete trellis work, on which is run plaster of Paris; flat boards being placed provisionally below the trellis as a mould, till the plaster is set.

It is now necessary to put the reader in possession of the means of calculating the strengths of the various timbers which enter into the composition of the three varieties of naked flooring already described, and to give, as guides in construction, such practical rules as experience has developed. This will best be done by taking each description of timber in its order.

Primarily, it may be remarked, that flooring timbers may be of such scantling as to be sufficiently strong for safety, and yet be deficient in stiffness. A slight deflection in the flooring would injure the ceilings of the apartment below; and for that and other obvious reasons, the rules for calculating the scantling of timbers in naked flooring are based on stiffness—or resistance to deflection, and not on absolute strength—or resistance to transverse breaking-strain.

Wall plates.—These, like all bearing timbers, should be increased in dimensions as the span becomes longer. It is not possible to give a rule by which to calculate this increase; nor is it necessary. Tredgold has laid down the following proportions as a guide; and they are practically safe:—

Rule.—Bearing, 20 feet.	Wall plates, $4\frac{1}{2}$ by 3 inches.
„ 30 „	„ 6 by 4 „
„ 40 „	„ $7\frac{1}{2}$ by 5 „

Where wall-plates extend over openings, and have to sustain the ends of timbers, their scantling must be calculated by the general rules for transverse strain. Wall-plates should be carefully notched together at every angle and return, and scarfed at every longitudinal joint. The notch joint is shown in Plate XXXIX., *Figs.* 16 and 19, and the scarf at Plate XXXIX., *Figs.* 1 to 15.

Single-joisted Floor.—The timber in the joists should be so disposed that these may be as deep as is consistent with the thickness requisite to prevent splitting in nailing the boards. The least thickness which it is safe to give is 2 inches.

To find the depth of the joist, when its thickness and the length of the bearing are given, and when the distance apart from centre to centre is 12 inches.

Rule.—Divide the square of the length in feet by the breadth in inches, and the cube root of the quotient, multiplied by 2·2 for fir, and 2·3 for oak, will give the depth in inches.

Example.—Required the depth of a joist when its length is 15 feet and its breadth 3 inches.

$\frac{15 \times 15}{3} = 75$, the cube root of which is 4·21. Therefore, $4·21 \times 2·2 = 9·26$ for fir, and $4·21 \times 2·3 = 9·68$ for oak.

But when joists are so thick as 3 inches, they injuriously affect the keying of the ceiling; and in the example above a better relation between the depth and thickness would have been obtained by making the latter 2 inches. In this case— $\frac{15 \times 15}{2} = 112·5$, the cube root of which is 4·4; which multiplied by 2·2 and 2·3, gives 10·56 for fir, and 11 for oak.

All single-joisted floors, it has been already said, should be strutted; and, according to the rule laid down, the rows of struts should not be more than 5 or 6 feet apart. Sometimes, to afford a better key to the plaster of the ceiling, the under sides of the joists are crossed with battens $1\frac{1}{4}$ by 1 inch, and 12 inches apart; and to these the laths are nailed. This process is in Scotland called *brandering.*

Trimmers and Trimming-joists.—The thickness of the trimmer is found by the rule given for binding-joists. The trimming-joists are made $\frac{1}{8}$ of an inch thicker for every joist carried by the trimmer.

In trimming, tusk tenons should be used. The tongue of the tenon should run at least 2 inches through, and be draw-pinned; and if it does not completely fill the length of the mortise, it should be wedged also. A proper fillet requires to be nailed to the trimmer to form a skew-back for the brick arch; and each trimmer should have two or more bolts, according to its length, to tie it to the wall.

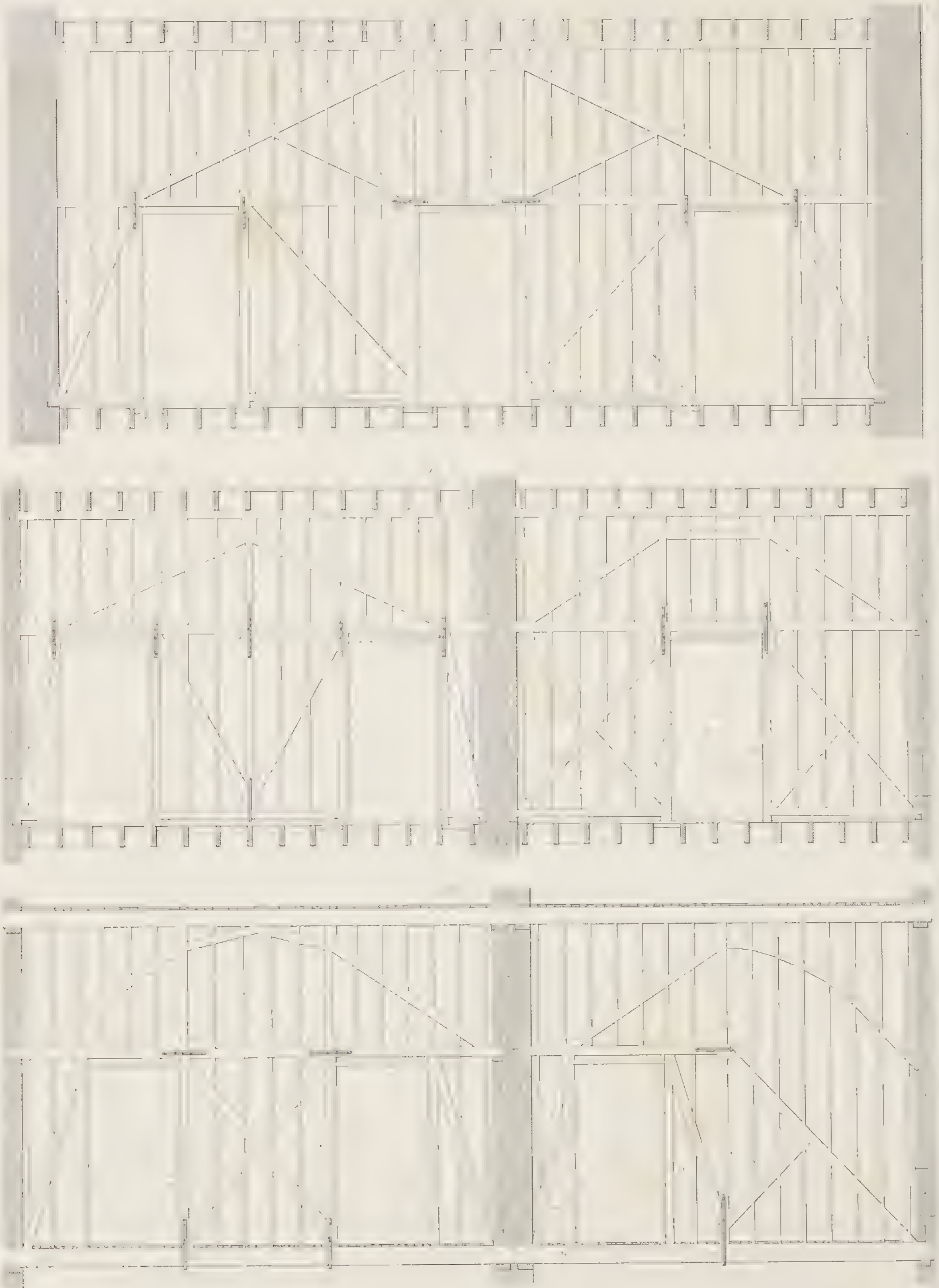
Binding-joists.—Binding-joists should not exceed 6 feet apart. Their depth is often, but not necessarily, regulated by the depth of the floor; and therefore it is necessary to know how to find the breadth when the length and depth are given, as well as to find the depth when the length and breadth are given.

To find the breadth, when the length and depth are given.

Rule.—Divide the square of the length in feet by the cube of the depth in inches, and the quotient multiplied by 40 for fir, and 44 for oak, will give the breadth in inches.

To find the depth, when the length and breadth are given.

Rule.—Divide the square of the length in feet by the breadth in inches, and the cube root of the quotient, mul-



tiplied by 3·42 for fir, and by 3·53 for oak, will give the depth in inches.

Girders.—To find the depth of a girder, when the length and breadth are given.

Rule.—Divide the square of the length in feet by the breadth in inches, and the cube root of the quotient multiplied by 4·2 for fir, and 4·34 for oak, will give the depth in inches.

Example.—Let the length be 20 feet clear, and the breadth 10 inches. Then $\frac{400}{10} = 40$, the cube root of which, 3·41, multiplied by 4·2 for fir, gives 14·32 inches as the depth, say $14\frac{1}{2}$.

To find the breadth, when the length and depth are given.

Rule.—Divide the square of the length in feet by the cube of the depth in inches, and the quotient, multiplied by 74 for fir, or 82 for oak, will give the breadth in inches. Take the same data as before—

$\frac{400}{2936} = \cdot 136$, which multiplied by 74, gives as the breadth 10 inches.

Ceiling-joists.—Divide the length in feet by the cube root of the breadth in inches, and multiply the quotient by 0·64 for fir, or 0·67 for oak, to obtain the depth.

Let the length be 6 feet and the breadth 2 inches. Then $\frac{6}{1 \cdot 26} = 4 \cdot 7$, which multiplied by $0 \cdot 64 = 3$ inches.

The foregoing rules apply to ordinary cases of floors, such as those of dwelling-houses. The greatest load on such floors is when they are covered with people, equal to about 120 lbs. per superficial foot, and allowing for the weight of the floor, altogether about 150 lbs. per foot. In warehouse floors, however, the absolute weight must be taken at about 24 cwts. to the yard superficial, or 300 lbs. per foot, and to allow for the shock caused by throwing down heavy goods, 380 lbs. to the foot should be assumed as the dead weight.

PARTITIONS.

Plate XLV.

Timber partitions are internal vertical divisions used in the upper stories of a building, to make the separations required in forming the apartments. When such apartments are more numerous than in the lower stories, the partitions should be so constructed as in no way to influence, by their weight, the integrity of the ceilings of the rooms beneath; and their weight therefore should be transferred, by the system of framing, to the immoveable points of the structure.

To accomplish this, trussed or quartered partitions are used. These are framed on the same principle as a king or queen post roof; and are equally capable of bearing a strain proportionate to the scantling of the timbers of which they are composed.

Timber partitions should not be used in dividing the ground floors into apartments, because of their liability to be affected by damp. Stones or bricks are the proper materials to use in such places.

Plate XLV.—The figures in this plate are all examples of trussed or quartered partitions.

Fig. 1 is a partition trussed on the principle of the queen-post roof. The object aimed at in this case is to resolve all the pressures or weights of the partition into vertical or downward pressure on the walls, which in the example before us is rendered easy by the symmetrical arrangement of the openings. For it will be readily seen that the pieces D D, with the intertie A A, the straining-piece *h*, and the struts *d*, acting in the same manner as roof principals, form a queen-post truss; the intertie A A being rendered continuous as a tie-beam by the straps at *a a*. The strut *c* serves to discharge the downward pressure at *m* to the wall; and the counter-struts, the pressure at *n* to the foot of the queen-post D. The actual stability of the partition, however, depends on the upper trussing; that is, on the framing composed of the tie A A, the posts D D, the principals *d d*, and the straining-piece *h*.

C is the headpiece of the partition, B its cill, *l* the door-posts, and *i i* the door-frame; *b b*, *b b* are the joists of the floors above and below. The counter-braces, such as *g*, prevent the sagging of the main struts, and give additional stiffness and firmness to the framing.

This partition is at right angles to the direction of the joists *b b*, and therefore when the door-posts do not fall upon a joist, it is necessary to support them by pieces, as *k*. The door-casing is shown, also the headpiece, and the joists of the floor above at *h k*.

Fig. 2, No. 1.—In this example, the intertie B, the post D, and the struts *g*, form a king-post truss. The door-posts *l*, are secured by the straps at *o* and *p*, the intertie is continuous, and the king-post is rendered so by the strap at *m*. The cill is sustained by the strap at *n*, and thus the whole system of the framing is dependent on the upper portion of the truss: *e* and *f* are the struts, and *k k* the doorcase; A the headpiece, and *h h* joists of the floor above.

In No. 2, the upper portion of the truss is on the queen-post principle. D is the intertie, which, as before, is the tie-beam; *e* is the strut forming the principal, and *f* the straining-piece. The door-posts A B are suspended by the straps *c c*, E is the cill, *d* a strut or brace, *g* a counter-brace, and C the headpiece.

Fig. 3, No. 1.—The partition in this case runs in the direction of the joists A and B, and the truss serves to give strength and stiffness to the floor. The upper portion of the truss, consisting of the intertie C, struts *e*, straining-pieces *f*, and queen-posts D D, is still in this example the main support of the framing. The straps *l l* tie up the joist to the queen-posts, which form one door-post of each door: the other door-post, *i*, is framed into the joist and intertie, and has its strut or brace *g*. Between the queen-posts are counter-braces *h*. The straps *k k* render the intertie continuous; *m m* is the door-case.

No. 2.—In this partition there is only one door at the side, and the framing is therefore not symmetrical. The intertie D, the post C, and the strut *h*, are the parts essential to secure the stability of the framing. The braces *f g i* are as before. The joist B is suspended by the strap *m*, and the strap *l* ties together the intertie D, the post C, and the brace *h*. A row of struts or dwangs (Scot.) *k k*, is introduced to give stiffness to the quarterings. This partition may be regarded as half of a queen-post truss, C being one of the posts, and the wall serving the purpose of the other.

The imperfections in joints, and the tendency in all timber to shrink, frequently cause settlements in framed partitions, and consequent cracks in the plaster. To diminish the risk of this damage, it is essential that all the timbers be well seasoned, and the joints made with the greatest exactness. It is advisable to have all partitions put up some time before they are plastered, so that any imperfection occasioned by warping or shrinking may be seen in time, and remedied.

The arrises of all timbers of, or exceeding, 3 inches in thickness should be taken off, to admit of a better key for the plastering. The distance apart of the quarterings, or filling-in timbers, should be adapted to the length of the laths, which is generally about 4 feet; and, therefore, when this is the case, the timbers should be about 1 foot apart from centre to centre.

TIMBER HOUSES.

Plates XLVI. and XLVII.

Houses and other edifices constructed of timber, and raised on plans of which the perimeters are right lines, are composed—

First, Of vertical walls of carpentry forming the façade and returns.

Second, Of interior partitions of carpentry, dividing the interior space horizontally into apartments.

Third, Of floors or horizontal partitions, dividing the interior space vertically into stages, stories, or floors.

Fourth, Of roofs which cover and defend the inclosure.

Fifth, Of stairs which afford access to the different stories.

The use of timber walls, doubtless, preceded the use of walls of masonry. Now, however, that the means of construction are multiplied, wooden structures are only erected in this country where other building material is scarce and timber plenty, when cheapness without regard to durability is aimed at, or when expedition in construction is the object.

Walls constructed wholly of carpentry would consume an immense quantity of timber, and would be more expensive than if built of brick or stone: the timber, therefore, in thick walls is used only in sufficient quantity to form a frame-work which shall insure the stability of the structure; and the interspaces or panels of the frames are filled in with masonry of small stones, with thin brick work, or with lath and plaster. This mode of construction is in the north called *post and pan* or *post and petrail*, and the square of framing is called a *pan;* but such erections are more universally called *half-timbered houses*.

The combination of principles in these timber erections varies very little. The general type of the compositions is presented in Fig. 470, and it may be traced in all the figures.

Ordinarily, to preserve the apartments and the timber from damp, the level of the first floor is raised considerably above the soil, on a wall of masonry. Frequently, the walls of the first story are formed entirely of masonry, and the carpentry work commences above this, carried up sometimes in the same plane, and sometimes projecting on corbels.

Every pan is composed of a ground-cill, which receives the tenons of the principal posts, and these posts receive the tenons of the horizontal beams, which are termed *bressummers*, and which serve to carry the floors, and are crowned at the top by beams corresponding to the ground-cill, and which, like it, are mortised to receive the tenons of the posts. These crowning beams are sometimes also named bressummers: when they support the feet of the rafters they are called *raising-plates;* but a general name for them is *capping-pieces*, which better describes their place and function.

The inclined timbers in the framing, termed braces, divide the parallelograms formed by the vertical and horizontal timbers into triangles, and thus preserve the integrity of their form. They, as well as all the other pieces, should be very exactly fitted at their abutments, to diminish as much as possible the creaking by the play of the joints, caused by the flexibility of the long timbers. Between the beams or bressummers, the door-posts, called *jamb-posts*, and the window-posts, called by old writers *prick-posts*, are framed. The horizontal pieces framed into these to form the heads of the openings are termed *transoms* and *lintels*, and those introduced between the principal horizontal timbers are called *interduces* or *interties*.

The posts which have no other function to perform than to sustain the edifice, are called *posts* simply.

The panels or spaces between the doors and windows, and between the different posts, are filled in with vertical pieces called *quarters*.

Pans which are of great length should be divided into bays, either equal or symmetrical, by principal posts, which, like those at the angles, should rise in one piece from the ground-cill to the capping-piece. As these interrupt the continuity of the bressummers, the ends of the bressummers which are framed into them should be tied together by iron straps within and without. All the beams, too, which are framed into the corner posts, and have return beams, should be tied in the same manner by a right-angled strap embracing the post.

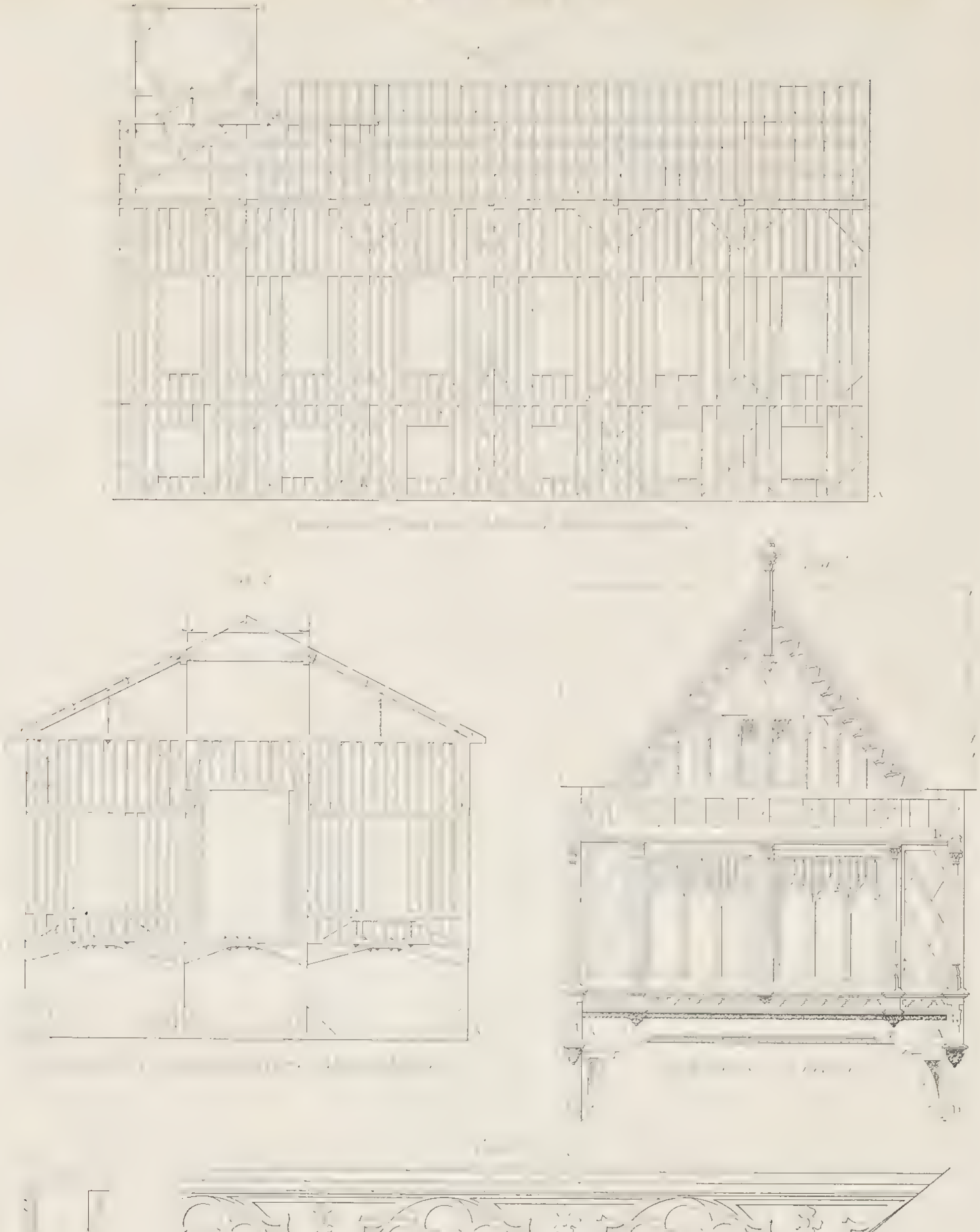
When the timber framing of the carcase is completed, all the intervals between the posts are, in the case of post and petrail construction, filled in with small stones or bricks set in good mortar. When the timbering is to remain visible, as is generally the case in such houses, the masonry or brick-work filling is done with great neatness, and the timbers are dressed on their exposed faces before they are framed.

When this mode of construction is not adopted, and the timbers are to be hid, the exterior and interior surfaces are lathed, and the space between is either left void or, which is better, filled with some non-conductor of heat, and then the lathing is covered with plaster and decorated with the usual architectural decorations of strings, cornices, architraves, &c.

In place of lathing and plastering the exterior surface, it may be covered with boarding, and wooden mouldings may be applied in decoration, as in Plate XLVI., *Fig.* 3.

To insure better connection between the masonry filling, the plaster, and the timber, it was formerly the custom to groove the latter, and to plant it all over with pins of wood: now this is seldom done.

In Sweden, where timber-houses are almost universally employed, the mode of construction is the same now as



it has been for centuries, and is also of the type here described.

A foundation plinth of rough granite is first laid to a height of 2 feet above the ground. On this are laid the ground-cills, with mortise holes for the uprights. The uprights are from 6 to 8 inches square, and are mortised to receive the bressummers, and are otherwise tied together by the interties, window-cills, lintels, and braces. When this framing is completed, it is covered on the inside with $\frac{3}{4}$-inch deal boarding, and on the outer side with two thicknesses of $\frac{3}{4}$-inch deal, the first laid horizontally and the second vertically.

The vertical joints are again covered by slips nailed to them. The space between the outer and inner lining is

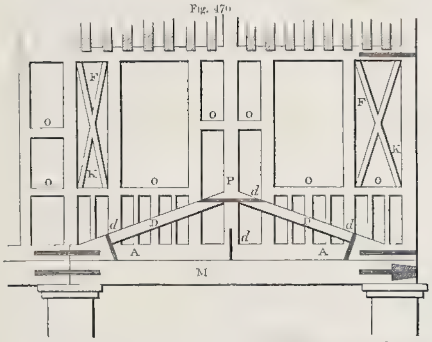
Fig. 469.

filled in with shavings, moss, or some non-conducting substance (see Fig. 469).

The lowest floor is double lined, and filled in between the linings in the same manner; and houses thus constructed are impervious to the colds of winter. A house of this kind can be erected in a few days, and where timber is abundant, costs very little. But its liability to be destroyed by fire renders it a very hazardous kind of building.

Fig. 470 is the elevation of part of one bay of a building constructed of wood on stone pillars. The ground-cill A is

Fig. 470



placed on the great pieces M, which form the lintels of the pillars. These pieces are called in French *poitrail*, evidently the same as the petrail of the north country, and which gives to this style of building the name of post and petrail.

In order to throw the weight as much as possible over the stone pillars, discharging struts D D are introduced at each story. These sustain the principal posts P, and are framed into them, and into the ground-cill, in the same way that a principal rafter is framed into its king-post and tie-beam, and is like it secured by iron straps *d*. The braces in the panels F K are halved on each other, and form the St. Andrew's cross, for the sake both of effect and stiffness. The horizontal pieces O O O are the interties.

The figures given in Plate XLVI., and about to be described, are the kind of constructions in timber which obtain in the present day. The more ancient edifices were constructed much in the same manner, the framing applicable to all such constructions not being susceptible of great variety. *Fig.* 3, Plate XLVII., is the elevation of the gable of a modern imitation of an ancient timber gable, in which the arrangement of the timber forms the principal decoration.

In designing pans of wood, the greatest care should be taken to make all the principal timbers coincide vertically, so that from the ground-cill to the headpiece the principal posts, story-posts, door-posts, and even the quarterings respectively of each story should be in the same vertical line, so that they may not have the effect of twisting or bending the horizontal timbers. For the same reason the openings of the doors and windows should be comprised within the same vertical lines. This sound rule of construction, void over void and solid over solid, is applicable to timber constructions as well as to those of stone or brick; and produces, by the symmetry and correspondence of parts which arise from its being adhered to, an effect which is always agreeable.

When it is necessary to make one or more of the openings of a greater width than the others, as a gateway for example, the panel in which it is made should, if possible, be carried up; and the weight of the intermediate framing above should be discharged by struts to the posts which form the panel, so that its lintel should have nothing to carry but the short quarterings between it and the cills of the windows above.

As the charge to be sustained by the timbers diminishes story by story as they ascend, it is customary and proper to diminish their scantling. The batter which ensues is confined to the exterior, the interior surface being kept in the same plane throughout. The effect of this is to increase the stability of the edifice by extending its base.

PLATE XLVI., *Figs.* 1 and 2.—In these the principles of construction described are exemplified, the ground-cill A, principal posts B′, bressummer E C, and diagonal struts B B and D D, form a truss which sustains the structure. The parts are connected by mortise-and-tenon joints, and secured by straps *a b c d e g*, &c. The principal posts, story-posts, and quarterings of both stories are in the same vertical lines.

Fig. 3 shows timber construction adapted to modern street architecture: A, the ground-cill; B F G, one of the principal posts; B, the angle principal; C D E, bressummers scarfed at the points *d*, *b*, and *e*, and secured by straps *a b c d f g*; K, an additional story-post at the angle.

PLATE XLVII.—*Figs.* 1 and 2 show the framing of the Townhall of Milford, Massachusetts. *Fig.* 1 is an elevation of the side of the structure: A A, the ground-cill; B B, bressummer; D D, intertie; C C, capping-piece. The principal vertical posts K L, K L, K L, correspond in number and position with the principals of the roof, and all the other principal timbers are in the same vertical lines. The same principle of construction is developed in the end elevation, *Fig.* 2, where A A is the ground-cill; A C, F F, principal posts, which are continued to form the tower shown in Plate XXXV^a; B B, bressummer; E E, E E, interties, forming trusses with B B by means of queen-bolts and struts *h h*; *g k m n* are braces, and D D, D D, interties above the windows and doors.

Fig. 3 is the elevation of a gable at Chester, a recent work, in which the ancient style is elegantly imitated, the arrangement of the timbers forming the principal decoration: A A is a lintel supported by the corbels, *a a*;

D D, principal posts; B B, intertie; C C, capping-piece; E E, story-posts; *e e e e*, quarterings, the panels between which are filled in with ornamental ribs.

Fig. 4 is a barge-board or gable board from a house at Droitwich, and *Fig.* 5 is an example of a gable-board from a house at Worcester.

BRIDGES.

A bridge is a platform supported at intervals to form a roadway over a river, valley, or other depression.

Bridges are as various in kind as the circumstances that necessitate their construction. They are formed of various materials, as timber, iron, stone, and brick, or of the combination of all these. In the timber bridge, for example, to the consideration of which this introduction properly refers, there may be piers or abutments of stone or brickwork, and the carpenter can only combine his timbers by the aid of the straps, bolts, hoops, screws, nuts, washers, and other ironwork supplied by the smith.

In bridges constructed with arches of masonry or brickwork, the aid of the carpenter is sometimes required in preparing the foundation by a cofferdam, or in making platforms of timber on which the stones or bricks are placed, and his utmost skill is, in large constructions, always called forth in designing and constructing the centres or mould on which the arch is formed.

Of all the materials used in bridge construction, timber, connected together by iron, is the most extensively available for the platform, and although liable to serious objections on account of its destructibility by natural decay or by accident, and its liability to change under hygrometric influence, yet the readiness with which it can be made available, its cheapness, and the ease with which it can be renewed, added to the improvements introduced by science to obviate its defects, render it in new countries, and especially in those where the material is abundant, such as America, one of the most important auxiliaries in civilization.

It is to these countries accordingly, and preferably to America, that it is necessary to look for the boldest examples of timber-bridge construction.

The most simple support for a roadway is a series of longitudinal timbers laid between two piers or abutments. When the span becomes considerable, single beams are insufficient and framed trusses become necessary. The consideration of the case of a single beam involves the principle of a framed truss. The same forces exist in both, the manner of resisting them alone is different.

The forces which act on a single beam, when loaded either uniformly or at certain points of its length, have already been investigated (page 123 *et seq.*); but it may be well to reproduce in this place a summary of the results, and to extend somewhat the consideration of the subject.

In any loaded beam, as we have seen, the fibres on the upper side are compressed, while those on the lower side are extended; and within the elastic limits those forces are equal. The intensity of the strain, also, varies directly as the distance of any fibre from the neutral axis. But there is another series of forces which has now to be considered.

Whatever be the form of a beam, it is always necessary that the area of cross section at the points of support be sufficient to resist the force tending to crush the fibres in a direction perpendicular to their length.

This resistance is proportioned directly to the area, and therefore the dimensions at the point of support must never be less than is obtained by making the resistance per square inch, multiplied by the breadth and depth, equal to the weight, or, in other words, by dividing the weight by the resistance per square inch, to find the area of section.

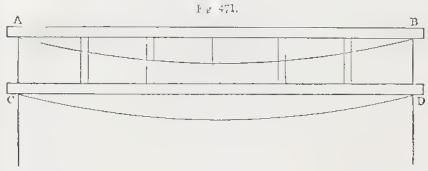
This vertical strain in a loaded beam occurs at all points between the middle and the ends. In the middle point it is almost nothing; at each end it is equal to half the weight of the beam and its load; and at intermediate points, it is proportional to the distance from the middle of the span—a consideration of great importance in bridge construction.

In what follows, an endeavour is made to place before the reader succinctly, and in a manner suited to the character of this work, the reasoning of Mr. Haupt on the principles of bridge construction.

If the parts of a beam near the neutral axis, which, we have seen, are little strained and oppose but little resistance, could be removed; and if the same amount of material could be disposed at a greater distance from the axis; the strength and stiffness would be increased in exact proportion to the distance at which it could be made to act. Hence, in designing a bridge truss, the material, to resist the horizontal strain, must be placed as far from the neutral axis as the nature of the structure will allow.

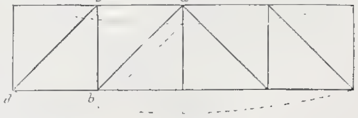
Suppose to the single beam A B (Fig. 471) we add another C D, and unite them by vertical connections, then it might

Fig. 471.



be supposed that we were doing as above suggested; that is, making a compound beam by disposing the material advantageously at the greatest distance from the neutral axis. But it is not so. There are only two beams resisting with their individual strength and stiffness the load, which is increased by the weight of the vertical connections, and they would sink under the pressure into the curve shown by the dotted lines. It is necessary, therefore, to use some means whereby the two beams will act as one, and their flexure under pressure be prevented. This is found in the use of braces, as in the next figure (472); and we shall

Fig 472.



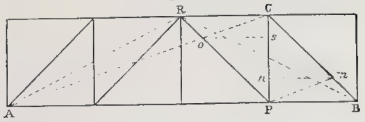
proceed to consider what effect a load would produce on a truss so formed.

The load being uniformly distributed, the depression in the case of flexure will be greatest in the middle, and the diagonals of the rectangles $a\,b$, $c\,d$, will have a tendency to shorten. But, as the braces are incapable of yielding

in the direction of their length, the shortening cannot take place, neither can the flexure. A truss of this description, therefore, when properly proportioned, is capable of resisting the action of a *uniform* load, as in the case of an aqueduct.

If the load is not uniformly distributed, the pressures will be found thus:—Let the weight be applied at some point C (Fig. 473), and represented by C P. Now resolve this into its components in the direction C A, C B, and construct the parallelogram P *m*, C *o*, then C *m* will represent the strain

Fig. 473.



on C B and C *o* the strain in the direction C A. By transferring the force C *m* to the point B, and resolving it into vertical and horizontal components, the vertical pressure on B will be found equal to C *n* and that on A equal to *n* P. That is, the pressures on A and B are directly proportional to their distance from the place of the application of the load.

In the same manner, if the load were at R, it would be discharged by direct lines to A and B.

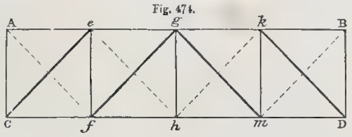
The effect of the oblique force C A acting on R is to force it upwards, and the direction and magnitude of the strain would be the diagonal of a parallelogram constructed on A C, C R.

The consequence of this is, that in a truss a weight at one side produces a tendency to rise at the other side, and, therefore, while the diagonals of the loaded side are compressed those of the unloaded side are extended.

Hence, while the simple truss shown in the last two figures is perfectly sufficient for a structure uniformly loaded, because the weight on one side is balanced by the weight on the other, it is not sufficient for one subjected to a variable load.

For a variable load, it is therefore necessary either that the braces should be made to resist extension by having iron ties added to them, or that other braces to resist compression in the opposite direction should be introduced; and thus we obtain a truss composed of four elements, namely,

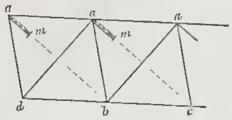
Fig. 474.



chords A B and C D (Fig. 474), vertical ties *e f*, *g h*, *k m*, braces *e* C, *g f*, *g m*, *k* D, and counter-braces A *f*, *e h*, *k h*, B *m*, or, in place of the latter, tie-rods added to the braces.

It has been shown that in any of the parallelograms of such a truss as has been described, the action of a load is to compress the braces *a d*, *a b*, and to extend the counter-braces *a b*, *a c*. Suppose, (Fig. 475) that the counter-braces have been extended to the length *a m*, and the braces compressed to an equal extent; then if a wedge be closely fitted into the interval *a m*, it will neither have any effect on the framing, nor will itself be affected in any way so long as the weight which has produced the flexure continues. But on the removal of the weight, the wedge becomes compressed by the effort of the truss to return to its normal condition. This effort is resisted by the wedge, and there is, consequently, a strain on the counter-brace equal to that which was produced by the action of the weight. The effect of the addition of a similar weight, therefore, would be to relieve the strain on the counter-brace, without adding anything to the strain on the brace *a d*.

Fig. 475



As the vibration of a bridge is caused by its effort to regain its normal form after the change of form produced by a passing load, it is evident that it will be much diminished by counterbracing in the way described.

There is thus required for the proper construction of a bridge at least four sets of timbers.

First, The horizontal main timbers, called *chords.*

Second, The vertical pieces uniting those, called *ties.*

Third, The main braces.

Fourth, The counter-braces; and to these may be added arch-braces, which will be noticed hereafter.

In proportioning these several parts, regard must be had to the following considerations :—

The chords being unsupported in the intervals between, the ties must be so strong that no sagging or deflection can take place. The braces must be incapable of yielding by lateral bending. Now, the proper proportions of these depend on the distance apart between the ties, and in arranging this, care must be taken to avoid extremes of number on the one hand, and weakness on the other.

To trace the effects of a weight through the system of timbers which compose the truss of a bridge, would be a very complex problem. It would, moreover, be beyond the scope of this work, and would exceed what has been assumed as the limit of mathematical knowledge of the majority of its readers. Such investigations, however, have been made, and their results assume the form of maxims of construction. Some of the most useful of these maxims, gleaned from the work of Mr. Haupt, are now presented to the reader; and his investigation of the weights and strains on the timbers and ironwork of the Sherman's Creek Bridge is given at length in p. 165–168.

As the parts of the frame act only in distributing the forces which are applied to it, and, whatever be the inclination of the braces, the pressure on the abutment and the strain upon the centre of the chords must remain the same, it might be inferred that the degree of inclination of the braces was of little consequence, but such is not the case. For the braces must not be so long as to yield by lateral flexure, and the chords must be supported at such intervals that no injurious flexure shall be produced by the passage of a load.

Again, as the ties approach each other the angle of the brace increases; and the number of ties and braces, and consequently the weight of the structure, is increased.

When the maximum load and the size of the chords are known, the limit of the intervals can be determined, by considering the portion of the chord between every two ties, as in the condition of a beam supported at both ends and loaded in the middle.

It has been shown that the strain upon the counter-braces is not increased by the passing of a load; and that by driving a wedge at the joint of the counter-brace, a strain can be permanently thrown on the brace, equal to that which would result from the passage of the maximum load. It will therefore be safe to calculate the strength of the counter-brace by the condition that it shall produce the required compression on the brace. This strain upon the counter-brace is equal to the pressure on the brace. Hence, as any accidental load that can ever act at a single point is small when compared with the uniform load, and it is to give the required immobility under the accidental load that the counterbracing is used, it follows that the counter-braces may be very small as compared with the other timbers.

It has also been shown that in a single beam supported at the ends and uniformly loaded, there exist horizontal and vertical forces at every point except the middle and the extremities. At the middle, the strains are altogether horizontal; but at other points, the distances to the extremities being unequal, the horizontal strains no longer balance each other, and the difference must be compensated by a cross strain on the fibres.

This vertical force, at zero at the centre, increases towards the extremities, where it is equal to one-half the whole uniform weight, and in this case the increase is proportional to the distance from the centre. Hence it follows that the ties and braces which resist the vertical forces may be smaller at the centre than at the abutments. Each successive brace, therefore, as it recedes from the centre, should theoretically be increased in size; but as this adds greatly to the trouble and expense of framing, it is better in practice to make them uniform in size, and to compensate for the additional strains at the ends by adding other braces called *arch-braces*.

In the construction of a bridge with arch-braces, the simplest plan is to depend upon the latter to sustain the weight of the structure, having only a light truss with counter-braces or diagonal ties to give connection and stiffness to the various parts, and to resist the action of variable loads.

Instead of arch-braces, arches are sometimes used, which are beneficial, and produce somewhat the same effects as the arch-braces.

An arch of timber cannot alone be depended on to sustain a variable load; it requires always to be connected with a system of trussing to give it the necessary stiffness.

The importance of having a beam continuous over its supports has been pointed out; and equally great advantages also accrue from having a bridge in which there are several spans in succession connected over the supports so as to be made continuous. The strength of the chords in the central span of a series would be double that of the same span disconnected; and the extreme spans would be stronger, in the ratio of three to two, than if disconnected.

In applying these results to practice, it is necessary first to determine the weight of the bridge and its load. The weight of the bridge is found by preparing a bill of timbers of assumed dimensions, and multiplying the number of cubic feet by the weight of a cubic foot of the material, which may be taken on an average at 35 lbs. The average quantity of material in the Howe bridges on the Philadelphia railroad is about 30 cubic feet per foot lineal; and therefore this may be assumed as a guide in calculations.

The greatest load a bridge can sustain would consist of locomotive engines, which would give 1 ton per foot lineal of the bridge.

Hence 1 ton per foot for the load, and half a ton per foot for the weight of the structure, may be assumed as a maximum load when the span does not exceed 200 feet.

The safe strain for timber will be considered as 1000 lbs. per square inch, and for iron ten times as much.

To find the strain on the chords.

1. *The strain of compression on the upper chord.*—Multiply half the weight of the bridge by the distance of the centre of gravity from the abutment (which is nearly a quarter of the span), and divide the product by the height of the truss, measured from the centres of the upper and lower chords.

Example.—Let the span be 160 feet, and the height 17 feet; required the cross section of the upper chord in the centre.

The weight at $1\frac{1}{2}$ ton per foot is 480,000 lbs.; and assuming the depth of the chords at 12 inches, the distance from centre to centre will be 16 feet.

Then, according to the rule, $\frac{480,000 \times 160}{8 \times 16} = 600,000$, as the maximum strain at the centre; which, divided by 1000 lbs., as the resistance per square inch, gives 600 square inches of section; which, divided by 12 inches, the depth of the chord, gives a total breadth of 50 inches, or 25 inches to each truss, if there are two trusses.

2. *The strain of tension on the lower chord at the centre.*—This is equal to the compressive strain on the upper chord; but from the occurrence of joints, the power of resistance is diminished. To compensate this, the quantity of material is increased to such an extent that the resisting area shall be obtained exclusive of the timber in which the joint occurs. A good practical way of doing this is to make the upper chord of three, and the lower chord of four timbers to each truss; and if a joint then should occur in each panel, each piece of timber should be equal to the length of four panels; and three of the four timbers should therefore contain sufficient resisting area for the whole strain.

3. *Strain at the ends of the chords.*—In a bridge of a single span, the horizontal strain at the end of the brace nearest the abutment will equal the weight on the brace, multiplied by the co-tangent of its inclination. If the inclination be 45°, the horizontal strain will be equal to the vertical weight. If the angle with the horizontal line is greater than 45°, the strain will be less than the weight. As this is generally the case, it is safe to assume the horizontal strain at the end of the chord as equal to the vertical force acting on the first brace.

This vertical force is half of the whole weight of 12 feet wide; and it is proper to take the strain on the whole panel as the minimum strain. The weight on one panel is 36,000 pounds; requiring a cross section of 36 inches, or 9 inches to a tie, and $11\frac{1}{4}$ to a brace. This cross section, for a brace of 20 feet long, is so small that it would yield with lateral flexure; and recourse must therefore be had to the formula for long posts, unless the braces are supported at the middle of their length.

The dimensions at the ends and at the centre having been obtained, the intermediate timbers should increase from the former towards the latter by regular additions.

4. *The strain on the Counter-braces.*—It has been shown that the strain on any counter-brace is equal to that produced by the action of a variable load on the corresponding brace. It will consequently be equal to the strain on the braces of the middle panel; and if each panel contains two braces and one counter-brace, the size of the latter should be uniform, and equal to 30 square inches, in the truss of the dimensions assumed. Hence, if supported in the middle, the counter-braces should be 6×5 inches.

5. *Horizontal Ties and Braces at top and bottom.*—The use of these is to give lateral stiffness to the bridge, and guard against the effects of the wind, which is the greatest disturbing cause. Assuming the force of the wind to be 15 lbs. per square foot, and the truss to be close boarded, and its height 18 feet, the total force over the surface would be 43,200 lbs. or 21,600 lbs. to each series of braces at the top and bottom of the bridge. If the calculation, therefore, is continued with the same dimensions as before, the half weight will be 240,000 lbs., and the cross section to resist it 240 square inches, or little more than one-third of the dimensions at the centre.

The dimensions at the ends and at the centre having been obtained, a uniform increase between the points can be made.

The size of the chords might be deduced from the formula applicable to a beam supported at both ends and loaded in the middle, in respect of that portion of them which lies between any two posts; but as the dimensions determined in this way are smaller, the rule already given is safer; and the excess of size is amply sufficient to resist the additional cross strain from any passing load.

6. *The strain on the Ties and Braces.*—The end braces which project from the abutments bear the whole of the load, and there is a decrease of strain to the centre. The weight of the bridge, as before, is 480,000 lbs., or 240,000 lbs. at each end; which, at 1000 lbs. per square inch, is 240 square inches of section for the ties if of wood, and 24 inches if of iron. If the panels be 12 feet wide, and the height, as before, 16 feet, the length of the diagonal or brace will be 20 feet, and the strain on it will be $\frac{240,000 \times 20}{16} = 300,000$ lbs. The section, therefore, will require to contain 300 square inches, which, divided among four braces, gives 75 square inches to each.

The strain at the middle is theoretically nothing, but in practice it is the same as that on the panel, on the above assumption. This would be estimated as the strain on a bridge produced by a uniform load; and if the bracing is in squares, the diagonals will be to the sides as $1 \cdot 4 : 1$ nearly. The strain on the end braces will be $\frac{21,600}{2} \times 1 \cdot 4 = 15,120$, which, at 1000 lbs. per inch, gives only 15·12 square inches to resist the strain. Practically, the end braces in this case might be 5×4 inches, and those at the middle of the span very much lighter. In the middle panel, they might even be omitted without injury.

Diagonal Braces and Knee-braces.—When the roadway is on the top of the truss, braces occupying the direction of diagonals to the cross section of the truss can be used to prevent side motion; but where the roadway is on the bottom, knee-braces must be used. Experience has shown that scantlings 7×5 are large enough for diagonal braces, and 6×5 for knee-braces.

Floor Beams.—The formula for these is the same as in the case of other floors. The case assumed by Mr. Haupt for the same truss is as follows:—Length of floor-beam between supports 14 feet, depth of same 14 inches, greatest load equal to 6 tons, applied at the centre; required the breadth, so that the deflection shall not exceed one-fortieth of an inch to a foot.

$$B = \frac{w\,l^2 \times \cdot 0125}{D^3}, \text{ or, substituting the figures,}$$

$$\frac{13,440 \times 14^2 \times \cdot 0125}{14^3} = 12 \text{ inches.}$$

Timber Arches.—Mr. Haupt considers that the usual course of making a truss sufficiently strong to resist the weight, and then adding arches as greater security, should be reversed; and that the arches should be made the main dependence, and a light truss be used in combination with them, to prevent change of form, and to give the proper support to the roadway. He assumes, for the sake of illustration, the same data as before, namely, the span at 160 feet, the rise of the arches, four in number, 20 feet, and the weight on the bridge $1\frac{1}{2}$ ton per foot.

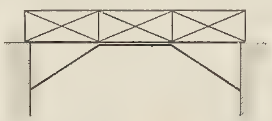
The weight is then 268,800 lbs. to each half of the bridge, and the strain on the arches in the centre is $\frac{268,800 \times 40}{20} = 537,600$ lbs., requiring 537·6 inches of cross section. Four arches 16 inches deep and 8·4 inches wide could supply the amount of material.

The compression at the ends will be to that at the centre as $\sqrt{40^2 + 20^2} : 40$, or as $\sqrt{2^2 + 1} : 2$; hence it will be $537,600 \times 1\frac{1}{8}$ nearly $= 601,055$ lbs., and will require 601 square inches of section; therefore, if the arch is 8·4 inches wide as before, its depth must be 18 inches nearly.

As in this case the whole of the weight is sustained by the arch, and the truss is used only to stiffen it and carry the roadway, the braces have no more strain at the ends than at the centre; and the principle of proportioning them in arithmetical progression from the centre to the end is no longer applicable.

With scarcely an exception, the examples of bridges contained in Plates XLVIII. and LVI. may be resolved into the following elementary figures:—

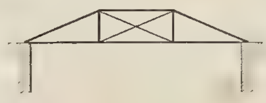
Fig. 476.



1. Trusses which are below the roadway, and which depend for their stability on the abutments.

Of these, Fig. 476 is the type, and the illustrations will be found in *Figs.* 3, 4, 6, and 7, Plate XLVIII.; *Figs.* 1 and 9, Plate XLIX.; *Fig.* 1, Plate LII.; *Fig.* 1, Plate LIII., and *Fig.* 1, Plate LV.

Fig. 477.



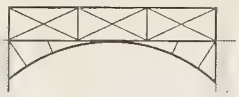
2. Trusses which are above the roadway, and have only vertical pressure.

Of these, Fig. 477 is the type, and the illustration will be found in Plate L.

3. Trusses below the roadway, composed of timber

arches, and ties and braces, but dependent on the abutments for resistance to lateral thrust, the type of which is Fig. 478.

Fig. 478.



4. Trusses above or below the roadway, composed of timber arches, and ties and braces, and which have only vertical pressure, the type of which is Fig. 479, and the illustrations *Figs.* 1, 5, and 12, Plate LIV.

Fig. 479.

5. Lattice trusses above the roadway, the illustration of which is *Fig.* 8, Plate LIV.

The foregoing analysis will enable the reader to find at a glance the illustration he requires, and with this key, the plates will now be described in their order.

PLATE XLVIII.—*Fig.* 1 is the elevation of a timber draw-bridge on the Gotha Canal, Sweden.

Fig. 2. Plan of the draw-bridge. In this, part of the floor timbers is removed, in order to show the framing, and the position of the rack for moving the bridge.

Fig. 3 is the elevation of the simplest form of trussing for a bridge, when the roadway is above the truss, and the abutments are sufficiently strong to resist the lateral thrust. A chord, B strut, C straining piece. Examples of the same kind of truss, applied in works recently executed, will be found in Plate XLIX., *Figs.* 9, 10, and 11, and Plate LV., *Fig.* 1.

Fig. 4. Elevation of a bridge truss, in which the chord-piece, A A, is in two lengths, joined in the middle of the span, and the fence of the roadway is used as an auxiliary truss, with a king-bolt, B. This would be improved in sustaining a variable load by introducing counter-bracing.

Fig. 5. The elevation of a bridge truss, composed of chord piece A, laminated arch B, struts and straining-piece C C, and cross-pieces D, connecting the framing. Further illustrations of the same principle in detail will be found in Plate LI., *Figs.* 1 and 6, in Plate LIII, *Fig.* 3, and in Plate LVI., *Fig.* 1.

Fig. 6 shows the elevation of a timber bridge of 34 feet span, with chord-piece A, two sets of struts C C, straining-piece B, and suspending-pieces D.

Illustrations of the extended application of this principle of framing will be found in the next figure in this plate, in Plate XLIX., *Fig.* 1, Plate LII., Plate LIII., *Fig.* 1, and Plate LV., *Fig.* 1.

Fig. 7. In this truss there are chord-pieces C, straining-pieces D *d*, struts E F G, counter-struts, or radial posts, H, transverse connecting pieces M M, radial straps *a b*, *a b*, cushion and straining-pieces to the under side of the truss K L, and cast-iron shoes, *c*, fixed to the abutment to receive the ends of the struts. The joints of the struts, and between the struts and straining-pieces, are secured by straps *e*, *d*.

Although from the contour of the under side of this truss, and the radiating posts and straps, it assumes the form of an arch, it has none of its characteristics: it is simply a truss of the same nature as those belonging to the class illustrated in *Fig.* 6; and the material is not so well disposed as in the examples of that class above referred to, and especially as in the following example.

PLATE XLIX.—*Figs.* 1 to 8 show the elevation, plan, and details of construction, of a timber bridge erected over the Spey at Laggan Kirk, by Telford. In this example, the material is employed most judiciously to obtain the greatest result by the smallest means; and the details, as in all the works of this excellent engineer, are worthy of careful study. The work belongs to Class No. 2 of the generalization. As the dimensions of the timbers are figured on the drawings, and the plan, elevation, and section explain themselves, it is only necessary to note that *Figs.* 4, 5, and 6 represent the details of the cast-iron sockets which serve to unite the struts to the straining-pieces, and *Figs.* 7 and 8, the details of the cast-iron shoe attached to the abutments to receive the ends of the struts.

Fig. 9 is a side elevation, *Fig.* 10 a transverse section, and *Fig.* 11 the plan, of part of a timber bridge, belonging to Class No. 1.

In this, there are the usual chord-pieces A, straining-pieces B, struts C. The piers are piles D D D, and are connected by two rows of waling timbers—one, *g g*, under the chord-pieces, and the other under the abutment of the struts. The chord-pieces are further secured to the heads of the piles by straps *c d*, seen in *Fig.* 11.

Fig. 10 is a section on the line L K of *Figs.* 9 and 11.

PLATE L.—Timber bridge over the river Don, at Inverury, on the Great North of Scotland Railway. This bridge belongs to the second class. It consists of 10 bays, or spans, four of which span the ordinary bed of the river Don, one spans a mill-lead, and five are land or flood openings.

It is situated about 200 yards above the confluence of the rivers Don and Ury, crossing the former at a considerable angle, adjacent to a great bend immediately above in the course of the river, and standing at the south end of a considerable flat, or haugh, which is liable to be flooded.

The bays are spanned by ordinary queen post trusses; this form being adopted in order to obtain the greatest height and clear water-way at the least expense.

In 1829 happened the greatest flood on record in Aberdeenshire: both the above rivers were swollen to an enormous extent; the level of the water, throughout the haugh referred to and on the site of the bridge, being within 2 feet 3 inches of the level of the under side of the tie-beams of the trusses. It was therefore necessary for the engineers to provide sufficient water-way for a similar flood; and after the most careful investigations of the history of that flood, the design of construction, and extent of openings of the viaduct, as now executed, were determined on.

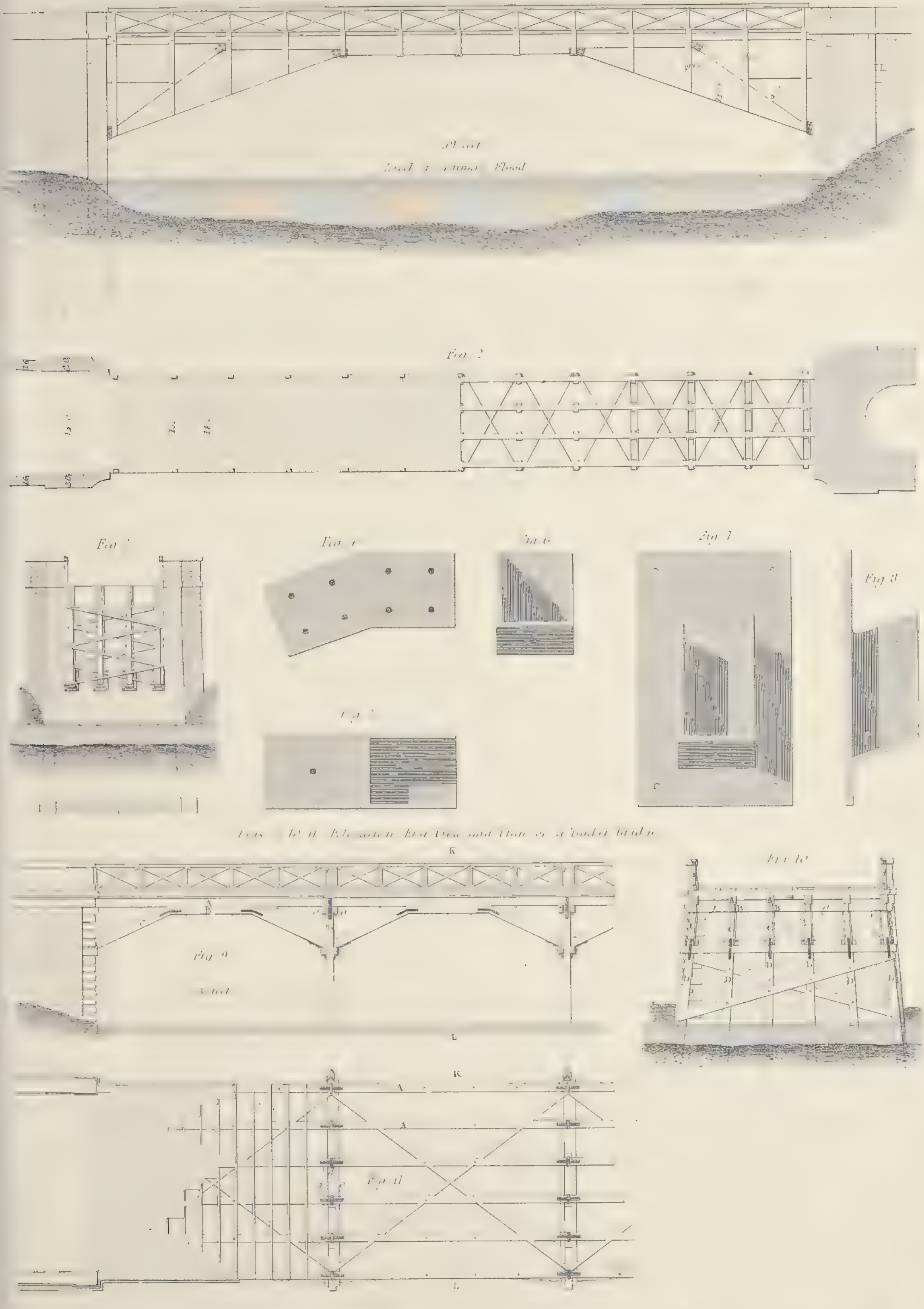
It is scarcely necessary to give a detailed description of the parts, as the accompanying drawings fully explain themselves; but a short general statement may not be out of place.

All the timber used in the structure is of the best Memel. The piles and braces of piers are 12″ × 12″ scantling. The head-pieces of the piers 12″ × 9″. The tie-beams of the trusses 12″ × 9″. The struts, straining-beams, and queen-posts of the trusses 12″ × 12″, and the diagonals 12″ × 8″.

All the wrought-iron work of the bolts and straps is of B.B. crown Staffordshire iron. The toes of the pier timbers are shod with Staffordshire boiler-plate; and the caps over the queen-posts, the shoes under the tie-beams, and the strap bars at the springing of the trusses, are of ordinary gray cast iron.

Preparations for the erection of the viaduct were commenced in the autumn of 1853, by the construction of a

TIMBER BRIDGES.



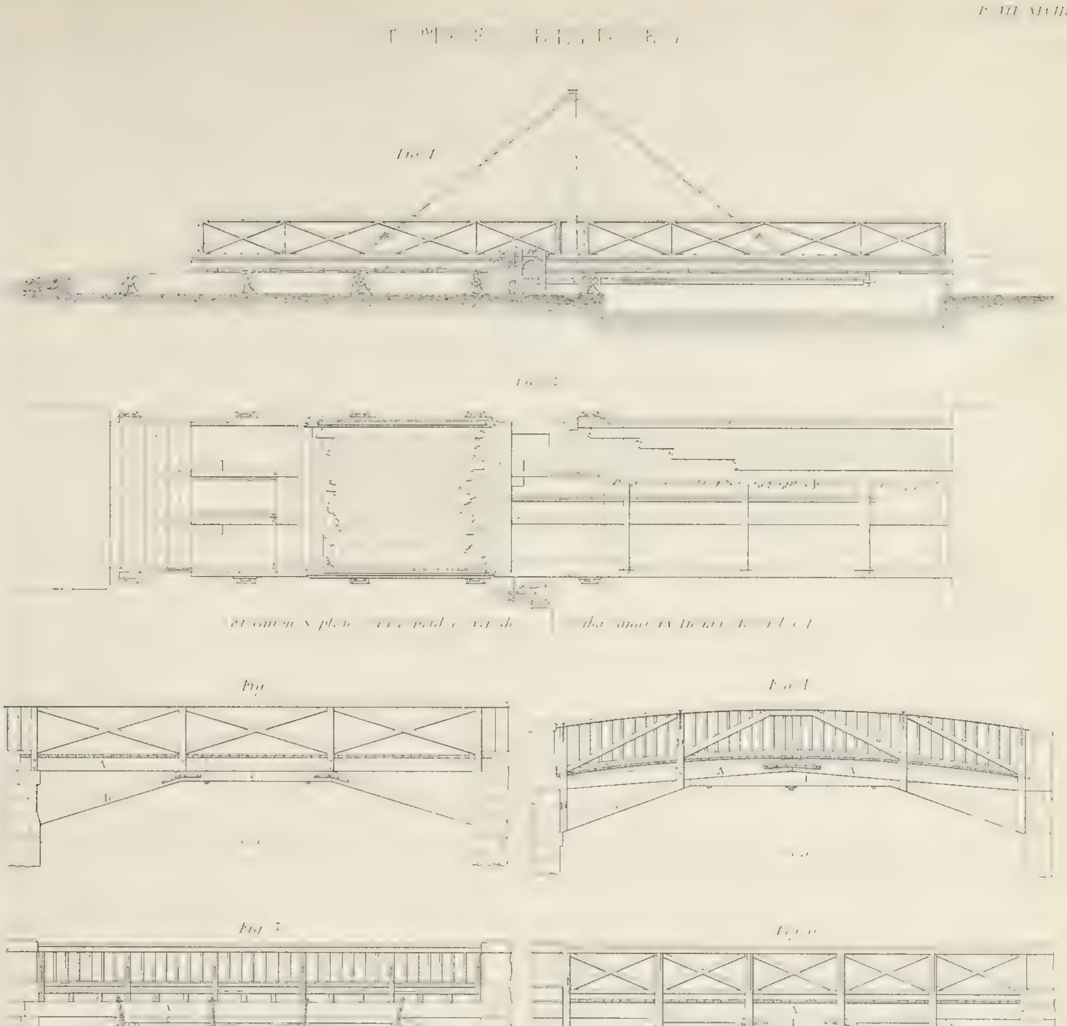


PLATE L.

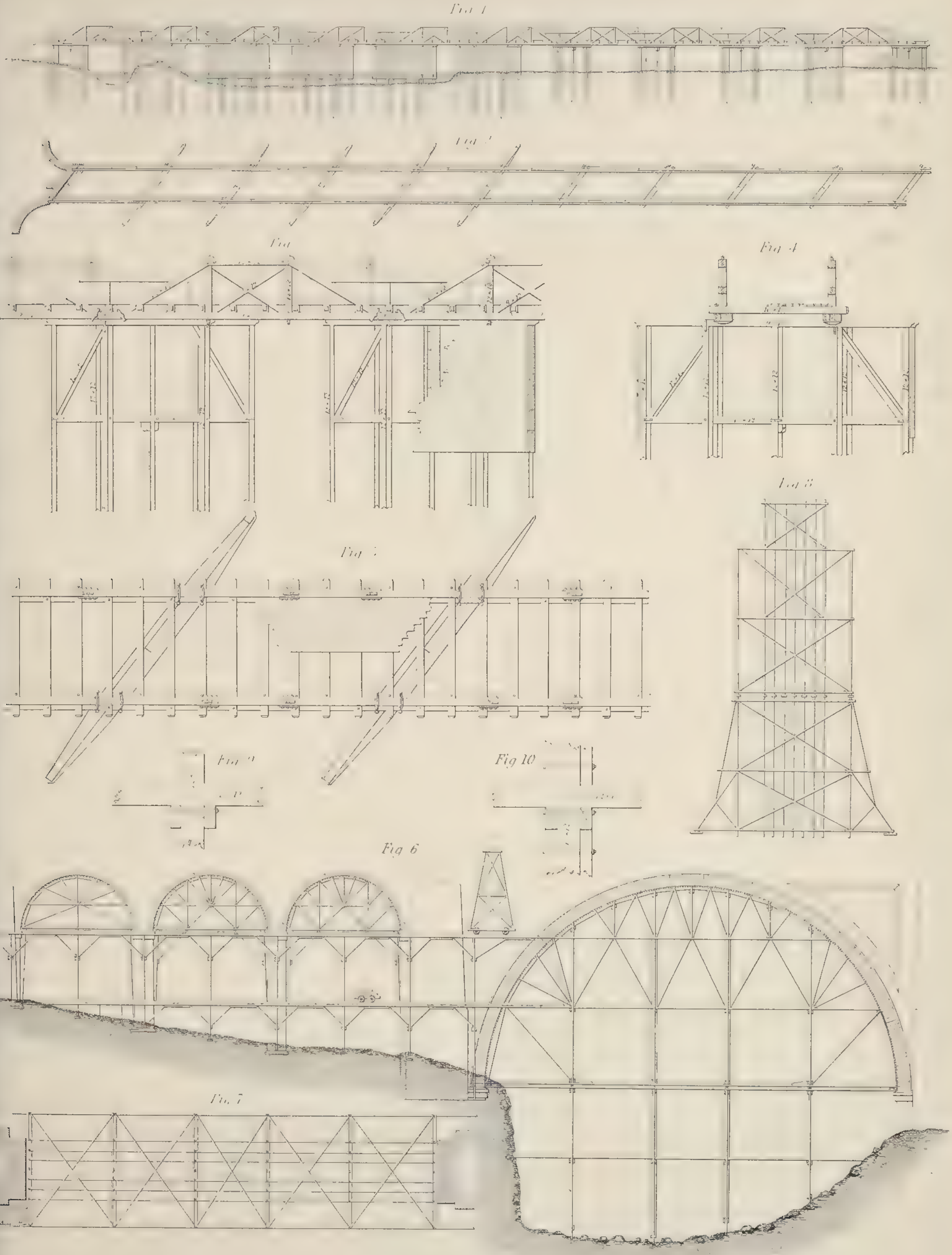
BRIDGES AND CENTRES.

Figs. 1 to 5 Shew Bridge over the River Don. Gt North of Scotland Railway

BY B. & E. BLYTH C.Es

Figs 6 to 10. Centring of Ballochmyle Viaduct, Glasgow and South Western Railway.

BY JOHN MILLER C.E.



Scale to Figs 1. 2. 6.

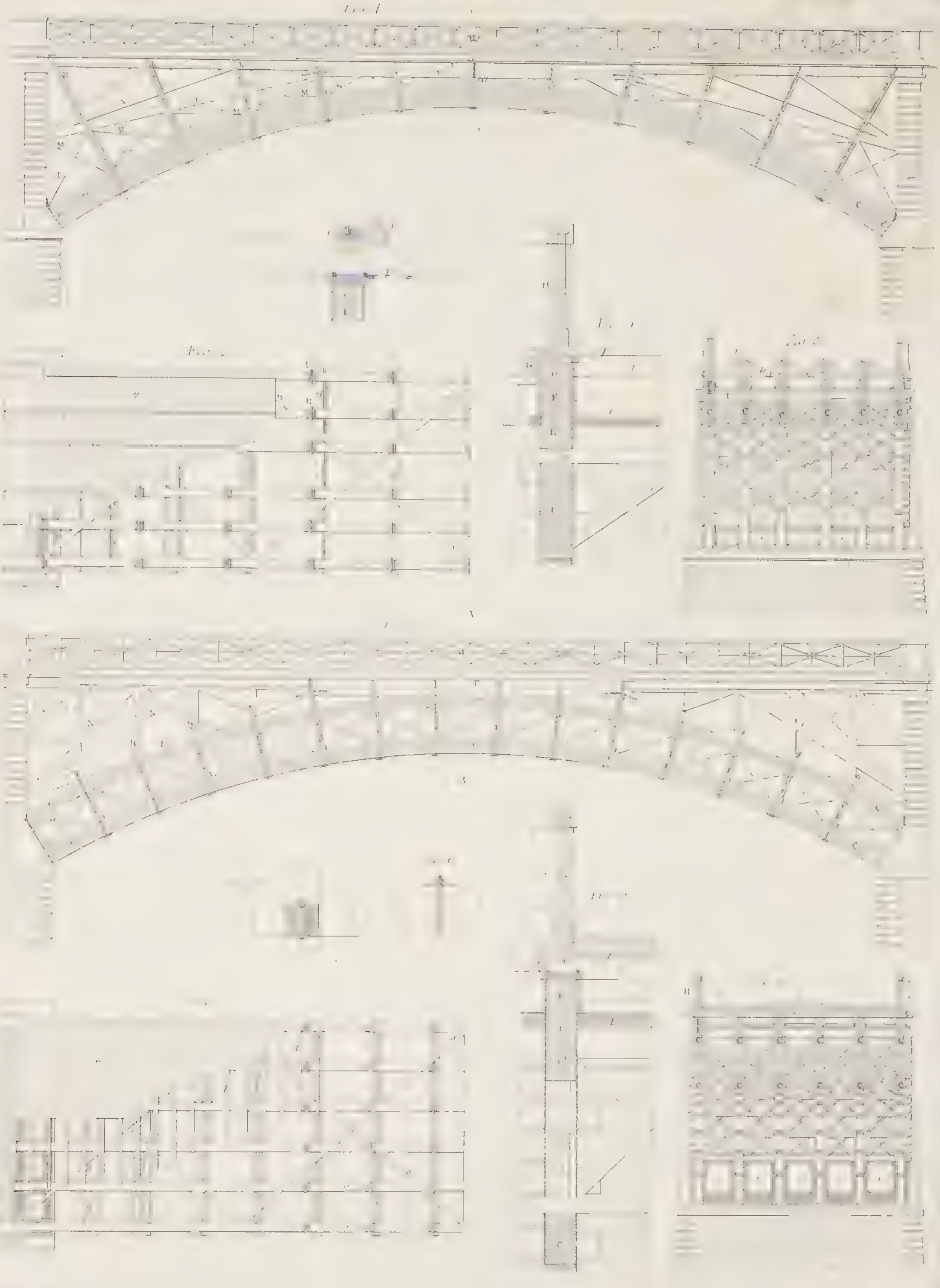
Feet

W. C. Joass Del.

W. A. Beever. Sc.

Feet

TIMBER BRIDGES.



temporary bridge across the Don, parallel to, and above the site of the viaduct, with side gangways at each pier for carrying the piling engines.

The piles were driven to varying depths, as shown in *Fig.* 1. They were shod with ordinary four-armed shoes weighing 20 lbs. each, and driven in till a perfectly firm rest was obtained.

The bed of the river consisted of large loose gravel and stones, lying on an under stratum of strong dark-coloured clay, into which the piles were driven several feet.

The water piers consist of seven piles, with longitudinal braces, diagonals, and cap-cills, arranged in such manner as to insure rigidity and strength. The distance between the extreme piles of each pier is 45 feet, this distance being considered necessary to resist the shocks given on the breaking up of frost in winter, when the river, swelling to a great height, hurls along with it enormous quantities of ice. Lumps of ice, weighing from 5 to 8 or 10 tons, have been seen shooting through this bridge with the velocity of seven miles an hour; and, in severe winters, sheets of ice half a mile in length frequently pass through.

The piers are all covered to a foot below the summer level of the water with 3-inch planks, spiked at the crossing of each timber. Filling-in pieces, 12″ × 6″, are introduced at the centre pile to receive this covering. Toe-pieces, 12″ × 6″, triangular in form, are faced on the outer piles; and these, and the ends of the covering, are further protected by sheets of boiler plate, 5 feet long, firmly bolted and spiked. Below the planking, the intervals between the piles are filled in with rough pitching of large rubble stones, and their exterior is surrounded with the same material.

All joinings of the timbers of the piers are secured by straps on each side 3″ wide by $\frac{3}{4}$″ thick, bolted together with $\frac{3}{4}$-inch diameter round bolts: where timbers cross each other, round bolts $1\frac{1}{8}$-inch diameter are used. The ends of the timbers are tenoned into mortises formed in adjoining beams. The diagonals of the piers are placed so as to form supports under the ends of the struts of the trusses.

Each truss consists of two parallel tie-beams, queen-posts, struts, straining-beam, and diagonals. The tie-beams are placed 9″ apart, and the queen-posts and struts pass through between them, having shoulders $1\frac{1}{2}$ inches deep on each side. The straining-beams, struts, queen-posts, and diagonals are all mortised and tenoned together, and fastened with straps, 3″ × $\frac{1}{2}$″, with $\frac{5}{8}$″ bolts. A round bolt $1\frac{3}{4}$″ diameter is passed through each queen-post and its cast-iron cap and shoe, and being firmly screwed up with nut and jam-nut, the whole truss is braced together, so as to give a slight camber to the tie-beam.

The struts of the adjoining trusses abut against each other, the abutment being about 8 inches deep. They are secured by straps, 3″ × $\frac{3}{4}$″, passed round the ties and screwed at the ends, to receive the cross cast-iron bars. The straps are increased in size in the centre to receive bolts which pass through the ties and strut.

The tie-beams are scarfed over the piers, and secured by bolts.

The roadway consists of transverse beams, laid 4 feet apart from centre to centre. The beams are 18 feet long, and 12 × 10 inches scantling: they are supported by the trusses, which are 14 feet apart, from centre to centre.

Each beam is fastened by bolts, 1 inch diameter, to one of the tie-beams at each end; and the whole surface between the trusses is covered with 3″ planking, on which the railway chairs are laid, and spiked through to the transverse beams.

The piles, the covering of the piers, and the roadway, are payed over with two coats of Archangel tar and pitch at a boiling heat; and the remainder of the timber work is painted three coats in white lead and oil.

All the timber is cleaned except the planking, which is rough from the saw.

The iron work was painted first one coat in red lead, and then two coats in black lead and oil.

During the winter of 1853–54, the temporary bridge was carried away by the breaking up of the ice; and two of the permanent piles, which were not connected with the others, and therefore unsupported, were broken over: beyond this no casualty occurred, nor was any special difficulty incurred in the execution of the viaduct.

The railway was opened in September, 1854; and though it has been severely tested by both summer and winter floods, the whole structure still continues in excellent repair. The engineers, however, thought it advisable to provide against extraordinary cases, and erected ice-fenders in front of each water-pier. These ice-fenders consist of three piles, braced, covered with planking, and faced with boiler-plate, similar to the end part of the water-piers. They are placed three feet clear of the piers, so as to receive any shock without allowing the main structure to participate in it.

These ice-fenders are not shown on the drawing.

Fig. 1 is a general elevation, and *Fig.* 2 a general plan.

Fig. 3, one of the bays drawn to a larger scale, with the dimensions of the timbers figured.

Fig. 4, transverse section through the bridge.

Fig. 5, plan of the bay shown in elevation in *Fig.* 3.

Figs. 6, 7, 8, 9 and 10 on this plate will be described in the section on "Centres."

Plate LI.—The figures on this plate illustrate Class 3. They are designs by Mr. White for railway and road bridges

Fig. 1 is an elevation of the framing of a railway bridge. It is a combination of a laminated arch with light masonry.

C C is the laminated arch, abutting at the ends on iron plates, *e e*.

F, the chord.

E, the straining-piece.

K N O, struts.

R S, R S, radial posts or braces, with double iron straps, and cross-pieces at R and S.

M L, M L, braces and counter-braces.

G, a continuation in timber of the torus-moulding of the piers.

H, the railing, or fence, which is braced and counter-braced, and so connected to the other framing by bolts (seen in *Fig.* 4) as to add strength and stiffness to the structure.

Fig. 2, a plan of part of the structure, which shows that it is composed of six parallel trusses, *o o o*, like that shown in *Fig.* 1, united by transverse bracing, *q q*, at each line of radial posts, and stiffened by horizontal braces, *w w*. At R R are seen the plates and cross-pieces connecting the straps of the radial posts.

Z shows a portion of the planking of the floor.

Fig. 3 is a transverse section of the bridge, on the line A B of *Fig.* 1, in which *c c c* are the arches, *e e e e* the abutment-plate, and *d* the cross-piece and transverse-bracing.

F, the chords.

E, the straining-pieces.

G, the torus.

H, the fence, *p* the floor, *f* the railway sleeper, and *g* the guide or guard piece.

Fig. 4 is an enlarged section, showing in greater detail C the arch, E F O G the horizontal timbers above it, and H the railing, *q* the cross timbers, *p* the floor, *d x y* the transverse ties and braces, and *t* a transverse iron tie at every radial post, bolted to the chords.

Fig. 5, an enlarged section, showing F O the chords, and the manner in which they are embraced by the straps and cross-pieces of the radial posts, *p* the floor, *f* the sleeper and rail, and *g* the guide-piece.

Fig. 6 is the elevation of a road bridge belonging to the same class as last example. It consists of two laminated arches in combination with straight trussing.

C C′, C C′ are the laminated arches, with radial posts, R *s*, and braces and counter-braces, *c* and *d*.

F is the chord.

E, the straining-piece.

K, the principal struts.

O O O, vertical posts, with struts or braces, N N, and counter-braces.

G is the timber continuation of the moulding of the piers.

H, the fence, consisting, as in the last example, of light framing of posts, rails, braces, and counter-braces.

Fig. 7 is a portion of the plan of the structure, showing the upper side of the trusses *o o o o*, the floor-timbers *q q*, the planking Z, the horizontal braces *w w*, and the cross-bracing at each line of radial posts.

Fig. 8, a transverse section of the bridge on the line A B, *Fig.* 6, in which C C are the laminated arches, E the straining-piece, F the chord, H the fence, *e e* the abutment-plate, of cast-iron, *s* the carriage-way, and *r r* the foot-paths of the road.

Fig. 9 is a section of one of the frames to a larger scale.

C, the lower arch.

C′, the upper arch, *c d* the brace and counter-brace, halved at their intersection.

E, the straining-piece.

F, the chord.

H, the fence.

x y, the cross-bracing.

t, an iron tie connecting the upper part of all the trusses.

q, the floor-timbers.

z, the planking.

G, wooden moulding.

Fig. 10 is the plan of the top of the straps which unite the arches to the truss, and *Fig.* 11, the side elevation of the same.

PLATE LII.—*Elevation, Plan, Section, and Details of the Timber Bridge over the River Tyne, at Linton, North British Railway.*—This bridge was originally constructed entirely of freestone. Between the abutments, from which the struts spring, there were two stone arches, with a pier in the centre of the river; but, owing to the insufficiency of the foundation of this pier, it was swept away by a flood of unprecedented magnitude in September, 1846, after the opening of the North British Railway: the abutments, however, remained uninjured. It became a matter of importance to repair this accident as soon as possible, to admit of the passage of trains; and with this view it was determined to erect, between the abutments of the arches which had fallen, the timber bridge shown on the drawings. This erection was put up very rapidly, owing to the simplicity of its construction; and it has been found to answer its purposes perfectly. The drawings, in themselves, are so complete as to render any detailed account of the structure unnecessary.

Fig. 1. Elevation of the bridge, the opening of which is 90 feet wide. The dimensions of all the parts are figured on the drawings, and the construction is shown in detail in *Fig* 4, Nos. 1 and 2.

The bridge belongs to the third class in our enumeration.

It consists of a built or laminated chord consisting of five planks, each 12 × 3, as seen in section, *Fig.* 4, No. 2. Immediately beneath this is a straining-piece, 12 × 6 inches, and 72 feet long; and struts C, 12 × 9.

Under this a series of eight transverse timbers serve to unite all the frames.

The next straining-piece is 12 × 6, and 54 feet 5 inches long; and the struts C are 12 × 9 inches. Under this is another series of six transverse pieces.

The next straining-piece is 12 × 6, and 36 feet 7 inches long. This has a series of four transverse pieces separating it from the next and lowest straining-piece A, which is 12 × 12, its struts also being 12 × 12.

The posts, E E, are 12 × 12 inches, and their straps are $3\frac{1}{2} \times \frac{1}{2}$ inch. The manner of securing the straps is shown in detail in *Figs.* 5 and 6. The lower ends of the struts are housed in radiating cast-iron shoe pieces, attached to a cast-iron abutment-plate, seen at F in *Figs.* 1 and 3, and at D in *Fig.* 2.

Fig. 2 is a plan of the structure, showing A, the truss frames; C, the transverse pieces; B, the horizontal braces; D, the abutment-plate; E, an upper plate of iron connecting all the trusses, seen also at G in *Fig.* 3, and in *Fig.* 4, No. 2; and F F, the rails.

Fig. 3 is a transverse section on the line A B, *Fig.* 1. G is the upper connecting plate, and F the abutment-plate.

Fig. 4. No. 1 is an enlarged elevation, and No. 2 an enlarged section of the truss and fence rail.

A, the lowest straining-piece; B B, straining-pieces; C C, transverse pieces; *f*, the upper straining-piece; *g*, the built or laminated chord; E E, straps.

The fence railing is framed with rails K, and capping piece I, posts G, and braces and counter-braces, H. A bolt, *e g f*, No. 2, passes through the upper rail K, the post G, and the chord and uppermost straining-piece, and thus unites the truss and the fence railing firmly together.

Figs. 5 and 6 show details of the head of the strap E, already referred to.

PLATE LIII.—*Figs.* 1 and 2 show the elevation and plan of a skew bridge, of Class No. 2, designed by Mr. White. The scantlings may be nearly the same as those in the last example.

Fig. 1 is the elevation. Each frame is composed of a

TIMBER BRIDGES,

PLATE LI

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Fig. 1

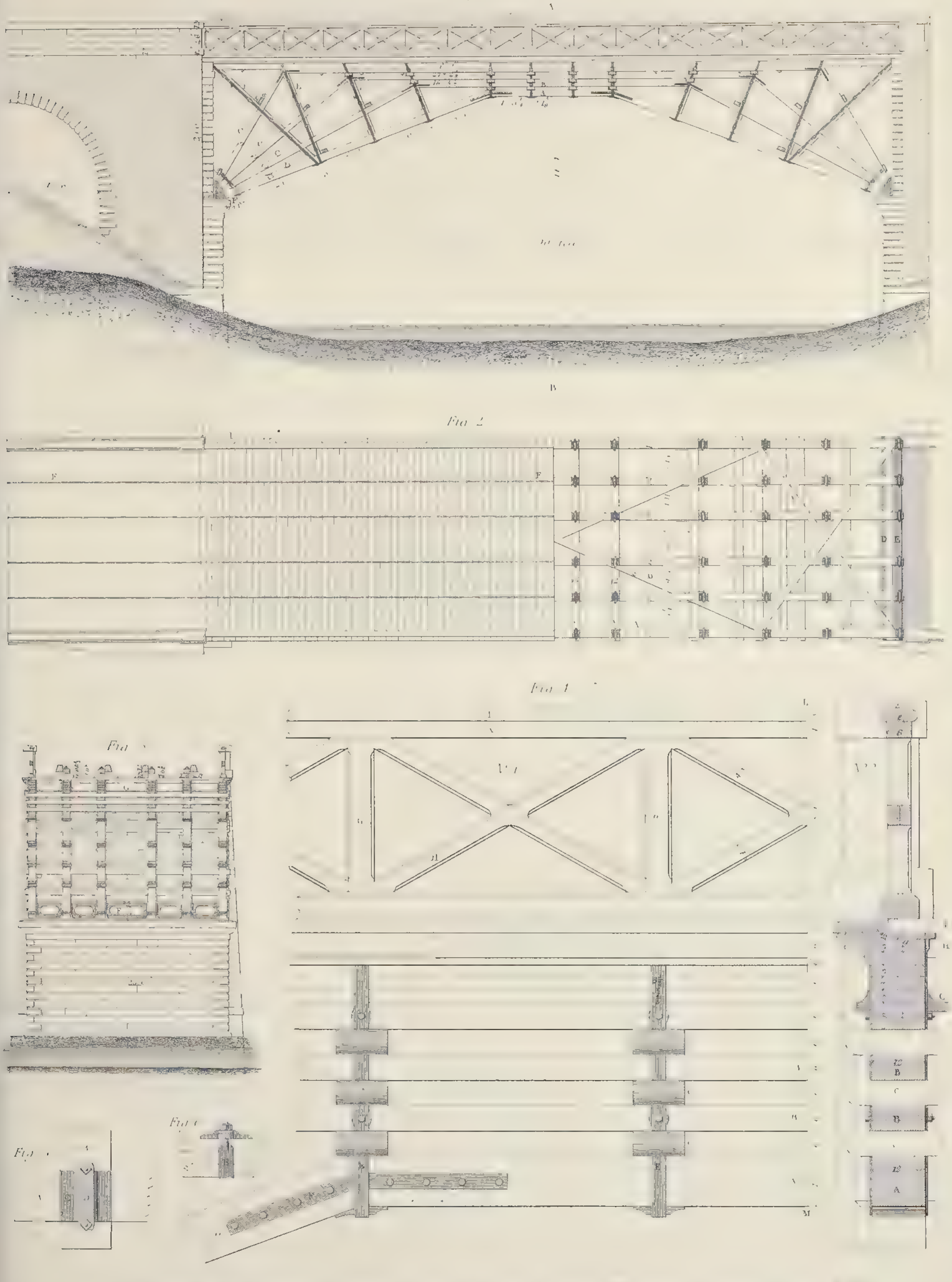

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Fig. 1

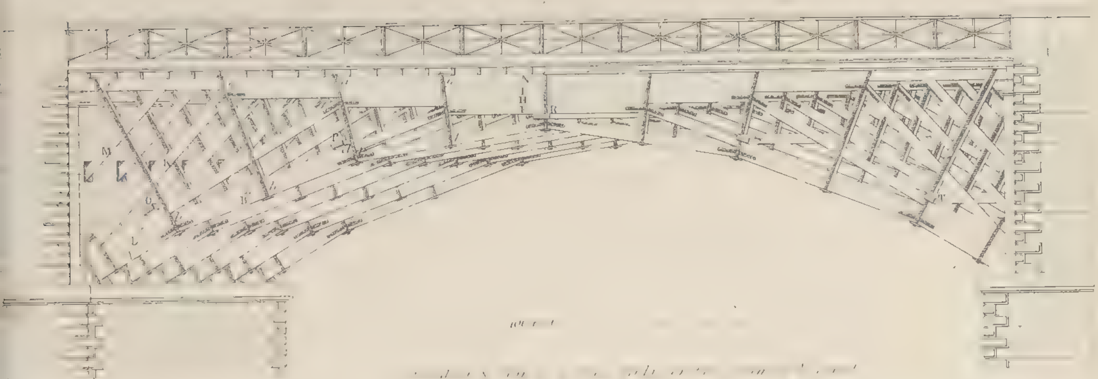


Fig. 2

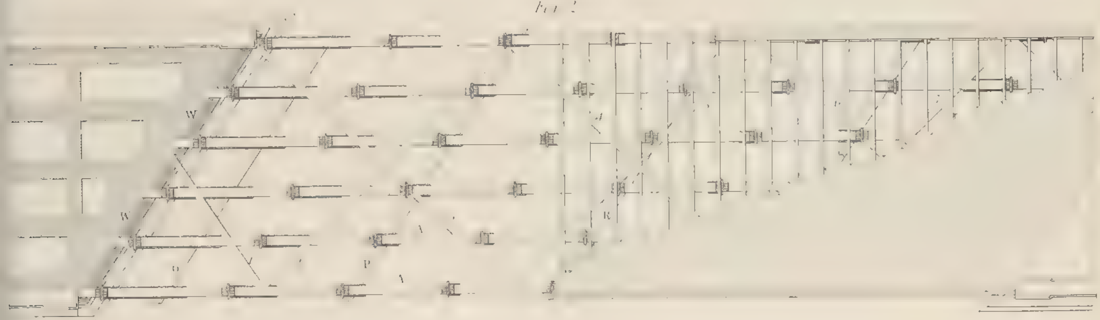


Fig. 3

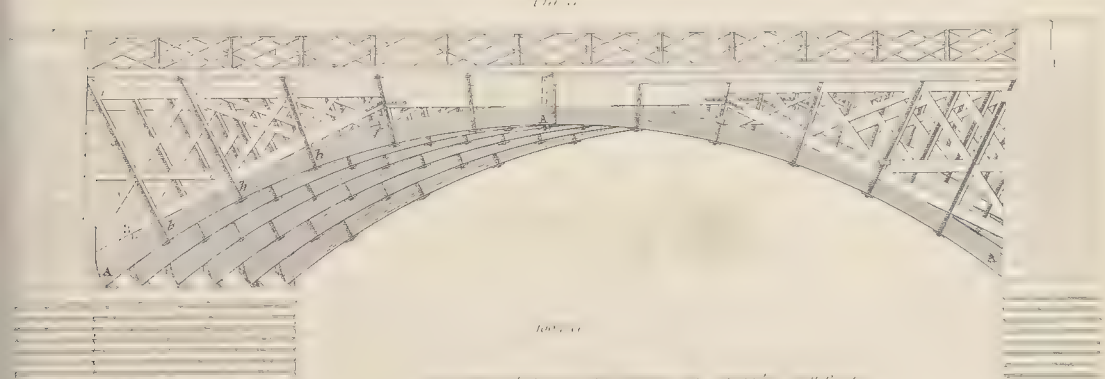
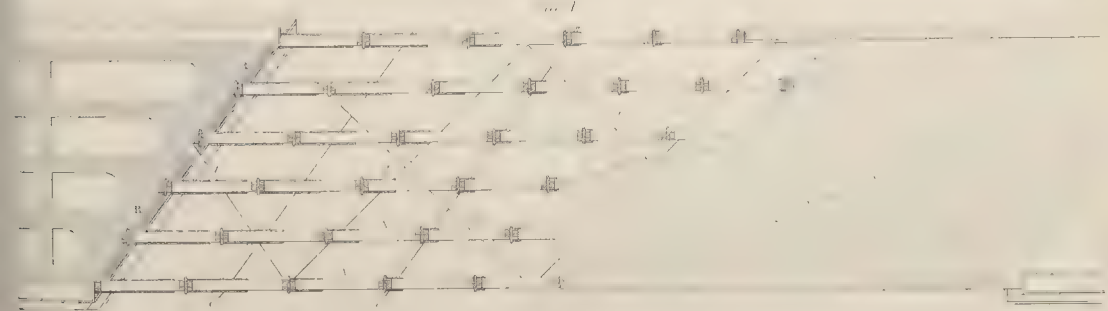


Fig. 4



20 ... 90 Feet

J. del ... W. Lowe sc.

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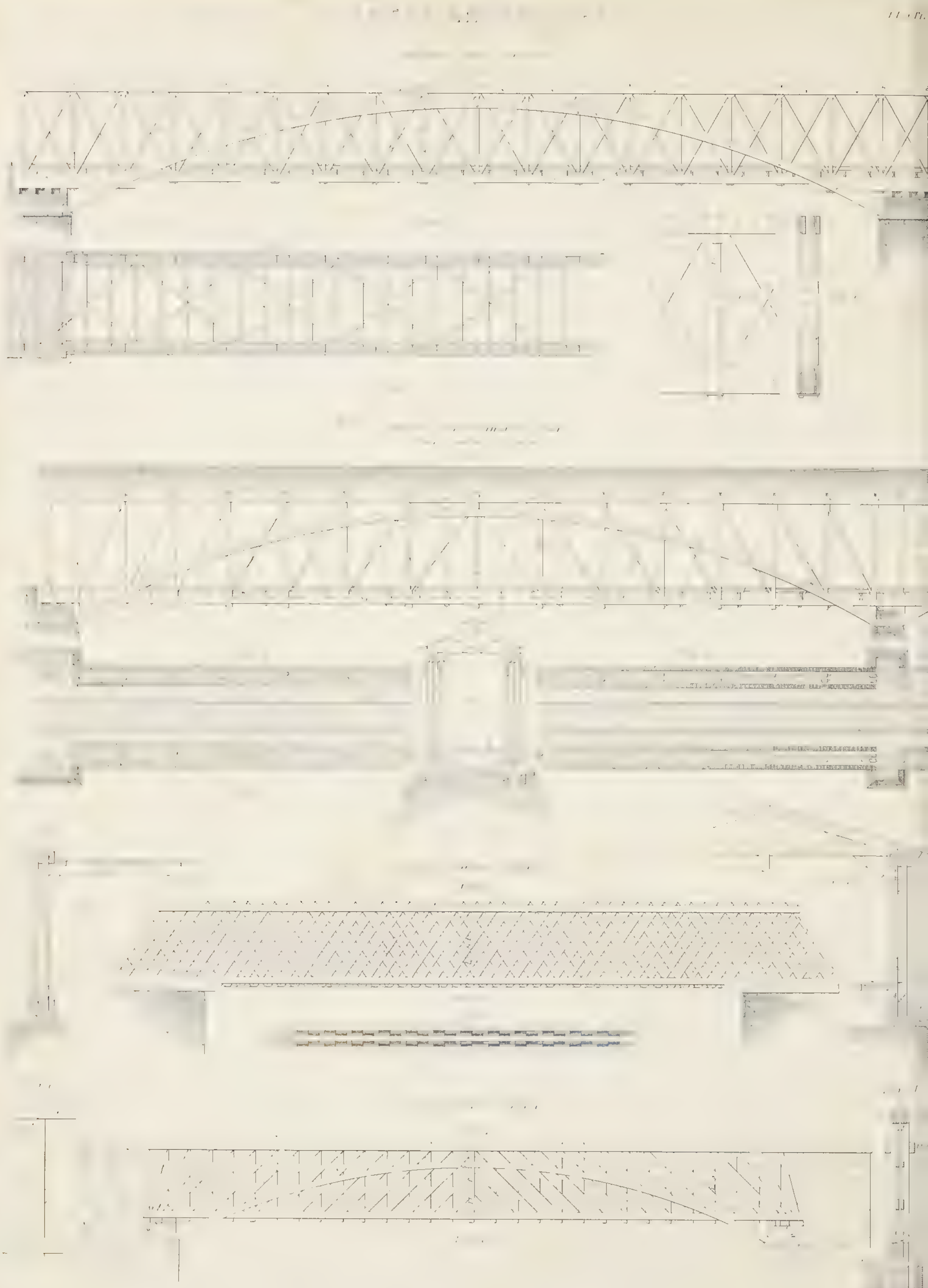

chord N, and straining-pieces L H F, and struts A B C, D E, G, K, and M; posts and straps *ab*, *a b*, *a b*; and transverse pieces O P R connect all the frames.

Fig. 2 is the plan showing the trusses A A, six in number, the connecting transverse pieces O P R S, and the horizontal braces, 1 2 3 4 5 6 7. The ends of the chords rest on a cast-iron wall-plate W W.

Figs. 3 and 4 show another design, by Mr. White, for a bridge composed of the combination of a laminated arch with the ordinary straight truss.

In the plan, it will be seen, there are no floor beams, but in their place planking close jointed, on which the flooring planks are laid, so as to cross them at right angles.

In the elevation, *Fig.* 3, there is shown a double chord F E, a straining-piece D, struts B C G, and posts and straps *a b*, *a b*, *a b*. Transverse pieces at *c* and *f* connect all the frames A A A to the laminated arches.

In *Fig.* 4, the plan, A A are the trusses, six in number; *c f*, the transverse pieces; R, the iron wall-plate; 1 2 3 4 5, the horizontal braces.

PLATE LIV.—*American Bridges:*

Fig. 1 is the elevation of a bridge belonging to Class 4. *Fig.* 2, part of the plan of the same. *Figs.* 3 and 4, the detail to a larger scale of the tension-posts, braces, and counter-braces, upper and lower chords, and their iron fastenings.

In this mode of combining an arch with a trussed frame, the arches are connected with the tension-posts, and the posts with the chords, by screw fastenings, as seen in *Fig.* 4; and all is so arranged as to admit of changing the position of the arches relatively to the chords, or of drawing together the chords without changing the position of the arches, and thus regulating and distributing the strain over the different parts of the bridge at pleasure.

The following are the directions of Mr. Steele, the patentee of this mode of construction, to be attended to in the erection of one of his bridges, extracted from Haupt's *Treatise on Bridges:*—

The truss must first be erected, provided with suitable cast-iron skew-backs to receive the braces and tension-posts; and the several parts of the chords should be connected with cast-iron gibs. Wedging under the counter-braces must be avoided, by extending the distance between the top skew-backs sufficiently to bring the tension-posts on the radii of the curve of camber of the bridge. The tension-posts must be about eight inches shorter than the distance between the chords; and, in screwing up the truss, care must be taken not to bring their ends in contact with the chords; but they must be equidistant, and about four inches from them. When the truss is thus finished, it must be thrown on its final bearings; and it is then ready to receive the arches, which should be constructed on the curve of the parabola, with the ordinates so calculated as to be measured along the central line of the tension-posts. They must be firmly fastened to the posts and bottom chords by means of strong screw-bolts and connecting plates, as shown at *d d*, and should foot on the masonry some distance below the truss, which can be done with safety, as the attachment to the posts and chords will relieve the masonry of much of their horizontal thrust. When a bridge so constructed is put into use, it will be found, as the timber becomes seasoned, that the weight will be gradually thrown upon the arches, which will ultimately bear an undue portion of the load. To avoid this, the camber must be restored, and the posts moved up, so as again to divide the strain between the truss and the arches.

This adjustment must take place once or twice in each year, until the timber becomes perfectly seasoned; after which, in a well-constructed bridge, but little attention will be required. Plates of iron should in all cases be introduced between the abutting surfaces of the top chords and arches; and all possible care taken to prevent two pieces of timber from coming in contact, by which decay is hastened: care should also be taken to obtain the curve of the parabola for the arches; as it is the curve of equilibrium, and of greatest strength, as has been shown by experiment.*

Bridges constructed on this plan, will be found to possess an unusual amount of strength for the quantity of material contained in them; and, if well built and protected, great durability.

Fig. 5. Elevation of a truss of Class 4.

Fig. 6. Plan of the same.

Fig. 7. Vertical section through the centre of the bridge.

The bridge is in two spans, each 148 feet 3 inches from skew-back to skew-back, or 154 feet 6 inches from the middle of the pier to the end of the truss. The pier is 3 feet 2 inches wide on the top, and 6 feet at the skew-backs.

The truss consists of three rows of top and bottom chords, and two sets of posts and braces. It is counter-braced by rods of inch iron between the braces. The panels increase in width from the end towards the middle of the span. The first are 9 feet $1\frac{1}{2}$ inches from centre to centre of posts, and the middle ones 12 feet $1\frac{1}{2}$ inches.

The quantity of materials in this bridge is given by Mr. Haupt as follows:—

Timber for one Span.

3 wall-plates	8	×	16	18	feet long	B.M.	576
20 chords	6	×	13	36	„	„	4,680
10 „	8	×	13	36	„	„	3,120
10 „	8	×	10	36	„	„	2,400
20 „	6	×	10	36	„	„	3,600
56 posts, yellow pine	9	×	12	23	„	„	11,592
4 king-posts	9	×	16	23	„	„	1,104
15 floor-beams ...	8	×	14	18	„	„	2,520
14 „	7	×	14	18	„	„	2,058
56 lateral braces...	$4\frac{1}{2}$	×	7	$8\frac{1}{4}$	„	„	1,213
3 „ „ ...	$4\frac{1}{2}$	×	7	13	„	„	103
30 roof-braces ...	4	×	5	17	„	„	850
56 check-braces ...	9	×	20	3	„	„	2,520
56 „ ...	9	×	23	3	„	„	2,898
60 main-braces ...	6	×	9	19	„	„	5,130
15 tie-beams ...	8	×	10	19	„	„	1,900
8 purlins	4	×	6	20	„	„	320
135 rafters	3	×	5	$10\frac{1}{2}$	„	„	1,772
15 roof-posts	4	×	5	3	„	„	75
30 knee-braces ...	5	×	5	5	„	„	312
16 track stringers ...	8	×	10	20	„	„	2,133
3300 feet B.M. $\frac{3}{4}$-inch sheeting for roof							3,300
56 arch-pieces ...	9	×	11	25	„	„	11,550
7000 feet B.M. inch boards, for weather-boarding, 20 feet long							7,000
							72,726

Weight per lineal foot, 1416 pounds.
No. of cubic feet per foot lineal, 40.

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* The parabola is the curve of equilibrium when no load is upon the bridge, and also when the load is uniform; but there can be no curve of equilibrium for the variable load of a passing train. Stiffness can be secured in this case, only by an efficient system of counter-bracing.

The plan proposed fulfils every condition of a good bridge.

Counter-brace Rods for one Span.

4 rods for	1st panels,	each 24 ft. 3 in. long,	1 in. diam.	97·0 ft.
4 "	2d "	" 24 " 2 "	1 "	97·0 "
4 "	3d "	" 24 " 8 "	1 "	98·7 "
4 "	4th "	" 25 " 0 "	1 "	100·0 "
4 "	5th "	" 25 " 2 "	1 "	100·7 "
4 "	6th "	" 25 " 8 "	1 "	102·7 "
4 "	7th or mid. pan.	26 " 0 "	1 "	104·0 "
			Total lineal feet	700·1

Weight in pounds at 2·65 per foot = 1855 pounds.

Arch Suspension Rods for one Span.

4 rods, each 6 feet 8 inches
8 " 10 "
8 " 13 "
8 " 15 feet 6 inches
8 " 17 " 2 "
8 " 18 " 2 "
} $1\frac{3}{8}$ inch diameter.

Total length 322 feet.
Weight at $4\frac{94}{100}$ lbs. per foot, 1590 pounds.

Lateral Brace Rods for one Span.

15 rods, each 16 feet 9 inches long, 1 inch diameter, 655 pounds.

Small Bolts for one Span.

60 bolts, through arches, 47 inches long, 1 inch diam.,	622 lbs.
60 bolts, through chords and posts, 34 inches long, $\frac{3}{4}$ inch diam.	255 "
30 roof-bolts, 36 inches long, $\frac{3}{4}$ inch diam.	135 "
224 spikes for braces, $\frac{3}{4}$ pound each	168 "

Mr. Haupt has given an analysis of the strains upon this bridge; and as it affords an example of his process of working out the problem of the stability of a timber bridge of this kind, the whole is here extracted:—

Dimensions and Data for Calculation of Bridge at Sherman's Creek.

Span at skew-backs	148 ft. 3 in.
Whole length of truss for one span... ...	154 "
Out to out of chords	20 "
Middle to middle of chords	19 "
Resisting cross-section of upper chords ...	400 sq. in.
Resisting cross-section of 6 lower chords, deductions for splice, check-brace, and bolt, and allowing for scarf-key...	280 sq. in.
Versed sine of lower arch...	20 feet.
Cross-section of 8 arches	800 sq. in.
Span 148¼. and rise 20, will give radius...	172 25 feet.
And 172·25, 152·25, and 74·125, express the proportion of the hypothenuse, perpendicular, and base of skew-back.	
Hypothenuse of skew-back covered by arches	18 inches.
Perpendicular " " "	16 "
Base " " "	7·6 "
Distance from skew-back to bottom of arch	4½ "
" " middle of skew-back to middle of chord	4 ft. 5 in.
Width from out to out of chords	16 " 2 "
" between chords in the clear	11 "
Distance from centre to centre of floor-beams	5¼ feet.
Weight of one-half span complete (77 feet)	120,000 lbs.
Distance of centre of gravity from point of support...	37 feet.
Weight of one-half span with load	275,000 lbs.
Distance between shoulder of post	15½ feet.

*Calculation of Truss without the Arches.**

Let x = distance of neutral axis from top chord.
$19 - x$ = distance of ditto from bottom chord.
P = pressure per square inch on top chord

$\frac{P}{x}(19 - x)$ = strain per square inch on bottom chord.
$x = 8{\cdot}3$ = distance of neutral axis from top chord.
$19 - x = 10{\cdot}7$ = distance of do. from bottom chord.
$P = 1532$ lbs. = pressure per square inch on top chord.
$(1532 \div 8{\cdot}3) \times (19 - 8{\cdot}3) = 1975$ lbs. = strain per square inch on bottom chord.

$$400\,P\,x = 280\,\frac{P}{x}(19 - x)^2.$$

$$400\,P \times 8{\cdot}3 + 280\,P \times \frac{10\,7}{8\,3} \times 10\,7 = 275{,}000 \times 37.$$

The bottom chords derive some assistance from the masonry; but as the roadway is on the bottom of the truss, little opportunity is given for wedging the lower chords; and for this reason the assistance to be derived from this service is not estimated.

Ties and Braces.

The weight upon the middle panel (12¼ lineal feet) is 45,000 lbs. To resist this there are four posts, the cross-section of each being 72 square inches, or the united cross-section 288, equivalent to 156·25 lbs. per square inch.

The distance between the shoulders of the posts being 15½ feet, and the width of the middle panel, exclusive of posts, 11½ feet, the diagonal will be 19·3.

The strain upon the diagonal will be $45{,}000 \times \frac{19{\cdot}3}{15{\cdot}5} =$ 56,000 lbs, which divided by the cross section of the four braces, will make the pressure per square inch $\frac{56{,}000}{2\ 6} =$ 260 lbs.

The expression for the limit of the resistance to flexure, $w = 4 \times \frac{9000\,B\,D^3}{l^2}$, gives the present case $w = \frac{9000 \times 9 \times 6^3}{19{\cdot}3^2}$ = 46,000 pounds, or for

The four braces...	184,000 pounds.
The actual pressure	56,000 "
Difference in favour of stability	128,000 "

The strain upon the end ties, which sustain the weight of half the bridge, will be 275,000 pounds, the cross-section being as before 288 square inches: the strain per square inch will thus be 955 pounds.

The width of the end panel being 8½ feet exclusive of posts, and the distance between the shoulders of the posts being as before 15½ feet, the diagonal will be 17·7 feet, and the pressure in the direction of the braces $\frac{275{,}000 \times 17\,7}{15{\cdot}5} =$ 314,000 pounds = 1451 pounds per square inch.

The limit of the resistance to flexure for the 4 braces is expressed by $w = \frac{9000 \times 9 \times 6^3}{17{\cdot}7^2} \times 4 = 223{,}000$ pounds.

As the pressure is 314,000 pounds, it appears that with the assumed weight of a train of locomotives, or one ton per lineal foot besides the weight of the structure, the end braces would yield by lateral flexure in the direction of the plane of the truss, if not supported in the middle.

If an intermediate support be used, the resistance will be quadrupled, and will be amply sufficient.

It is also necessary to examine whether the braces, if supported in the middle in the direction of the plane of truss, could yield laterally in the direction of the perpendicular to this plane: the relative resistances in the two

* The reader will readily discover that Mr. Haupt, in general, uses the approximative round numbers in his calculations, for the sake of simplicity.

cases are as $6 \times 9^3 : 9 \times 6^3$, or as $9 : 4$. The limit in this case would therefore be $\frac{223,000 \times 9}{4} = 502,000$ pounds, which is more than the pressure (314,000 pounds).

It appears therefore from this calculation, that if the arches are omitted, the end braces should be supported in the middle by diagonals in the opposite direction. As an additional security, the depth should be increased to nine inches. In the other panels, they should diminish gradually to the middle of the span, where the original dimensions are sufficient.

Floor Beams.

The floor beams are 7×14 inches, width in clear between supports 11 feet, distances from centre to centre $5\frac{1}{2}$ feet.

The weight on the drivers of a locomotive, 18 tons, may be considered as distributed nearly equally over 3 floor beams, which will give 6 tons for each beam.

$6 \times 3 \div 5{\cdot}5 = 3{\cdot}3$ tons = the equivalent weight in the middle of the beam

$R = \frac{18\,w\,l}{b\,d^2} = \frac{18 \times 6600 \times 11}{7 \times 14^2} = 952$ pounds = maximum strain per square inch.

Lateral Braces.

The lateral braces are $4\frac{1}{2} \times 7$ ins., and 8 feet long. The prevalent winds are in a direction nearly parallel to the axes of the bridge, so that its exposure is not great. Assume as the basis of a calculation that the sides are closely boarded 20 feet high, and that the perpendicular force of wind may be 15 pounds per square foot: the whole pressure upon one span will be say 45,000 pounds. As there is lateral bracing both above and below, this pressure would be resisted by 4 lateral rods 1 inch diameter = 3·14 square inches, or 14,330 pounds per square inch.

The proportional strain upon the lateral braces would be $\frac{45,000 \times 8}{5} = 72,000$, to resist which, are four braces $4\frac{1}{2} \times 7 = 126$ square inches $\doteq 571$ pounds per square inch. The bearing surface at the joints does not much exceed one-half the area of the cross-section, consequently the actual pressure at the joints will be about 1000 pounds.

The limit of flexure of the four braces is expressed by $w = \frac{9000 \times 7 \times 4\frac{1}{2}^3}{8^2} \times 4 = 360,000$ pounds nearly.

The maximum pressure is 72,000 pounds.

Difference in favour of stability, 288,000 pounds.

The lateral braces cannot yield either by crushing or bending, and are, therefore, amply sufficient.

Could the bridge, if not loaded, be blown away?

The weight of one span has been found to be 240,000 pounds.

The resistance to sliding would be... ...	120,000	pounds.
The pressure of wind	45,000	„
Difference in favour of stability ...	75,000	„

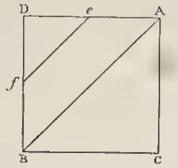
Could the bridge yield to the force of the wind by rotation around the outer edge of the chord?

The effect of the wind, 45,000 pounds, acting with a leverage of 10 feet, would give for the disturbing force	450,000	pounds.
The resistance, = weight of bridge × half-width from out to out = 240,000 × 8 =	1,920,000	„
Difference in favour of stability ...	1,470,000	„

Strain upon the Knee-braces.

Let A C B D (Fig. 480) represent the cross-section. The effect of the pressure of wind on A C is equivalent to half that pressure applied at the point A. A force at A tends to produce rotation around B and C, which may be resisted by a brace in the direction of the diagonal A B.

Fig 480.



The pressure upon the brace will bear to the force at A the proportion of the diagonal to the side A D. If the brace be removed, the pressure must, nevertheless, still continue; and if it be resisted by a brace $e\,f$, the pressure upon $e\,f$ will be greater than that upon A B, in the proportion of A D to e D; because D is a fulcrum, and A D and e D the leverages of the acting and resisting forces. If $e\,f$ is parallel to A B, which is generally a very favourable direction, the lengths $e\,f$ and A B will be in proportion to the distances D e and D A, and may be substituted for them. In the present case, the force of wind, 45,000 pounds, acting with a leverage of ten feet, will give its moment 450,000, or 225,000 pounds acting at a distance of 20 feet. The length of the diagonal is $\sqrt{20^2 + 16^2} = 25{\cdot}6$ feet, and the strain in the direction of the diagonal $\frac{22,500 \times 25{\cdot}6}{16} = 36,000$ lbs.

The length of the knee-braces being 5 feet, the strain upon them will be $36,000 \times \frac{25{\cdot}6}{5} = 184,000$ pounds. This is resisted by 15 braces (one to each post). The cross-section of each is 25 square inches; but, as the bearing surface of the joint does not extend over the whole surface of the section, the resisting portion will be reduced to 15 square inches. The strain per square inch will therefore be $\frac{184,000}{15 \times 15} = 818$ pounds.

For the resistance to flexure of the fifteen braces, $w = \frac{9000 \times 5 \times 5^3}{5^2} \times 15 = 3,375,000$, or about 20 times the pressure.

The strain upon the bolts at D, will be to the vertical component at A, in the proportion of D e to e A, or as $5 : (25{\cdot}6 - 5)$. The vertical component at A, $= 22,500 = \frac{\text{A D}}{\text{A C}} = 22,500 \times \frac{16}{20} =$ say 17,000. Hence the strain upon the 15 bolts will be $17,000 \times 4 = 68,000$, or 4533 pounds to each bolt, or 10,000 pounds per square inch if the bolts are $\frac{3}{4}$ inch diameter.

Pressure upon the Arch.

For this calculation we have, from the table of data,

Span, 148 feet.

Distance of centre of gravity from abutment, 37 feet.

Rise of arch, 20 feet.

Proportion of hypothenuse, perpendicular, and base of skew-back = 18, 16, and 7·6.

Cross-section of 8 arches, 800 square inches.

$800 \times \frac{16}{18} = 711$ proportion to resist horizontal thrust at skew-back.

$800 \times \frac{7{\cdot}6}{18} = 338$ square inches to resist vertical pressure at skew-back.

The weight for one half span loaded is 275,000.

$$800 \times 20 \times P = 275{,}000 \times 37.$$

$P = 448 =$ pressure, per square inch, on arches, in middle.

The resisting cross-section at the skew-backs is the same as at the crown.

The pressure is greater in the proportion of the hypothenuse to the perpendicular: it will therefore be $448 \times \frac{18}{16} = 504$ lbs.

The arches are therefore more than sufficient to sustain the whole weight.

When both systems act as one,

The data required to determine the strains upon the chords and arches are,

Distance from middle of upper to middle of lower chord	19 feet.
Distance from middle of skew-back to middle of lower chord	4·2 „
Distance from middle of top chord to middle of arch	3·5 „
Cross-section of upper chords...	400 square in.
„ lower „	280 „
„ arch at crown	800 „
„ „ skew-backs	711 „

Let x = dist. of top chord from neutral axis.

„ $x - 3{\cdot}5$ = „ arch at crown „

„ $19 - x$ = „ bottom chord „

„ $23{\cdot}5 - x$ = „ arch at skew-back „

„ P = pressure per sq. in. on top chord.

„ $\frac{P}{x}(x - 3{\cdot}5) =$ „ „ arch at crown

„ $\frac{P}{x}(19 - x) =$ „ „ bottom chord.

„ $\frac{P}{x}(23{\cdot}5 - x) =$ „ „ arch at skew-back, horizontally.

The equations in this case are,

$$400\,P\,x + \frac{P}{x}\,800\,(x - 3{\cdot}5)^2 + \frac{P}{x}\,280\,(19 - x)^2 + \frac{P}{x}\,711\,(23{\cdot}5 - x)^2 = 275{,}000 \times 37,$$

$$\text{and } 400\,P\,x + 800\frac{P}{x}(x - 3{\cdot}5)^2 = 280\,\frac{P}{x}(19 - x)^2 + 711\,\frac{P}{x}(23{\cdot}5 - x)^2.$$

From the second of these we find $x = 11{\cdot}8$.

Consequently the distance of the neutral axis will be,

Below top chord	11·8 feet.
„ arch	8·3 „
Above bottom chord	7·2 „
„ skew-back	11·7 „

These values substituted in the first equation will give $P \times 222{,}000 = 7{,}175{,}000 \times 11{\cdot}8$, or

$P = 381$ lbs. = pressure per square inch on top chord.

$381 \times \frac{8{\cdot}3}{11{\cdot}8} = 268$ lbs. = pressure per square inch on arch, at top.

$381 \times \frac{7{\cdot}2}{11{\cdot}8} = 232$ lbs. = strain per square inch on lower chord.

$381 \times \frac{11{\cdot}7}{11{\cdot}8} = 377$ lbs = strain per square inch on perpendicular of arch, at skew-back.

Vertical Pressure.

Assuming that the weight sustained by each system will be in proportion to its power of resistance, the greatest weight that the truss can sustain will be the limit of flexure of the braces in the end panels. This has already been found to be 223,000 pounds, which will be produced by a vertical pressure of $\frac{223{,}000 \times 15{\cdot}5}{17{\cdot}7} = 195{,}282$ pounds: this is the extreme limit of the power of resistance of the end braces.

The proportion of surface at the skew-back which resists the vertical pressure is 388 square inches. If we suppose the vertical pressure on the base of the skew-back to be the same per square inch as the horizontal pressure upon the perpendicular, it will be capable of resisting 180,830 lbs.: this, deducted from the whole pressure, . . 275,000 „ will leave for the portion to be sustained by the braces . . . . 94,170 lbs. which is below the resisting power. The actual limit of the resisting power of the arch is very great; but assuming that in practice it is not safe to exceed 1000 pounds per square inch, the proportions of the weight sustained by the truss and arch would be,

For the truss $275{,}000 \times \frac{108{,}663}{338{,}000 + 108{,}663} = 66{,}880.$

And for the arch $275{,}000 \times \frac{338{,}000}{446{,}663} = 208{,}000.$

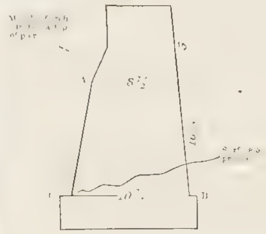
These numbers will give for the strain per square inch on the arch, $\frac{206{,}100}{338} = 615$ lbs.

For the end braces $\frac{66{,}880 \times 17{\cdot}7}{15{\cdot}5 \times 216} = 353$ lbs.

It has been stated that the bridge at the western end is sustained by an abutment-pier: it is proper to examine whether the resistance which that is capable of opposing is sufficient to counterbalance the thrust of the arch, on the supposition that it should bear the whole of the load.

The dimensions of the abutment-pier are given in Fig. 481, except the length, which may be taken at 16 feet.

Fig. 481.



We will examine the conditions of equilibrium on the supposition that rotation takes place around the point B. The disturbing force is the horizontal component of the thrust of the arch = 358,750 lbs. acting with a leverage of $16\frac{1}{2}$ feet: its moment will therefore be $358{,}750 \times 16\frac{1}{2} = 5{,}919{,}375$.

The resistances are:—

1. The weight of the masonry above C B = 110 perches, of 3750 lbs. = 412,500 lbs. The distance of centre of gravity from B is 5 feet; the moment will be 2,062,500.

2. The adhesion of the mortar, estimating it at 50 lbs. per square inch, or one-half the tabular strength of hydraulic cement, will be, on a surface of 160 sq. ft., = 1,152,000 lbs., and its moment, with a leverage of 5 feet, = 5,760,000 lbs.

3. The vertical pressure of the arch itself, 275,000 lbs., acting with a leverage of 9 feet, will give a moment, $275{,}000 \times 9 = 2{,}475{,}000$.

The sum of the moments of the resisting forces will be		2,062,500
		5,760,000
		2,475,000
Total		10,297,500
Moment of disturbing force		5,919,375
Difference in favour of stability	=	4,378,125

As this difference is less than the adhesion of the mortar, it appears that an abutment pier of dry masonry of the same dimensions would be overturned.

It has been supposed, in this calculation, that the arch bears the whole weight, and that the abutment resists the whole thrust. The actual horizontal thrust, with the two systems acting together, was found to be $377 \times 711 = 268{,}047$. The moment will be $268{,}047 \times 16\frac{1}{2} = 4{,}422{,}775$. The resistance, omitting the strength of the mortar, $= 4{,}537{,}500$. From which it appears that if we disregard the adhesion of the mortar, the system as a whole would be very nearly in a state of equilibrium, the difference being in favour of stability. The practice of the writer in proportioning abutments on rock foundations is, to disregard the adhesion of the mortar, throwing this, whatever it may be, in favour of stability: there is so little uniformity in the strength of mortar, and so much liability to cracks occasioned by jars, when partially set, that it is not safe to depend much upon it. If the proportions and weight of an abutment do not prevent it from overturning, without taking the strength of the mortar into consideration, it is too weak.

When the base is to any extent compressible, it is not sufficient that the disturbing and resisting forces should be in a state of equilibrium—a condition which requires the resultant of all the forces to pass through the middle of rotation; but it is proper that the resultant should pass through the middle of the base.*

Summary.

Span	148	ft. 3 in.
Width of pier on top	3	„ 2 „
„ „ skew-back	6	„
Timber in one span	72,726	„
No. of cubic feet per foot lineal	40	„
Width from out to out of chords	20	„
„ middle to middle of chords	19	„
Versed sine of lower arch	20	„
Radius	17,255	„
Weight of timber per lineal foot	1,416	pounds.
Weight of iron in one span	5,280	„
Weight of half-span loaded	275,000	„
Strain upon floor beams per square inch	952	„
„ lateral brace-rods per square inch	3,444	„
„ lateral braces	571	„
„ knee-braces per square inch	818	„
Pressure per square inch on top chord ...	381	„
„ „ „ arch at crown	268	„
„ „ „ lower chord...	232	„
„ „ „ arch at skew-back	615	„
„ „ „ end-braces ...	353	„
„ „ „ middle braces	260	„

Fig. 8 is the elevation of the common lattice bridge; *Fig.* 9, a section of the same when the roadway is above the latticed sides; and *Fig.* 10, a section when the roadway is supported on the under side of the lattice. *Fig.* 11, plan of one of the latticed sides.

Although when first introduced the lattice construction at once obtained great favour from its simplicity, economy, and elegant lightness of appearance, yet experience has shown that it is only adapted for small spans and light loads, unless fortified by arches or arch braces. When well constructed, however, it is useful for ordinary road bridges where the transport is not heavy. On the subject of lattice bridges, Mr. Haupt makes the following pertinent remarks introductory to his notice and description of the kind of construction called the improved lattice, shown in *Figs.* 12, 13, and 14:—

"One of the first defects apparent in some old lattice bridges, is the warped condition of the side-trusses. The cause which produces this effect cannot, perhaps, be more simply explained than by comparing them to a thin and deep board placed edgeways on two supports, and loaded with a heavy weight: so long as a proper lateral support is furnished, the strength may be found sufficient; but when the lateral support is removed, the board twists and falls.

A lattice-truss is composed of thin plank, and its construction is in every respect such as to render this illustration appropriate. Torsion is the direct effect of the action of any weight, however small, upon the single lattice.

A second defect may be found in the inclined position of the tie. All bridge-trusses, whatever may be their particular construction, are composed of three series of timbers; those which resist and transmit the vertical forces are called ties and braces, and those which resist the horizontal force are known by the names of chords, caps, &c.

In every plan, except the common lattice, these ties are either vertical, or perpendicular to the lower chords or arches; and, as the force transmitted by any brace is naturally resolved into two components, one in the direction of, and the other at right angles to the chord or arch, it would seem that this latter force could be best resisted by a tie whose direction was also perpendicular. The short ties and braces at the extremities, furnishing but an insecure support, render these points, which require the greatest strength, weaker than all others; this defect is generally removed by extending the truss over the edge of the abutment, a distance about equal to its height, or to such a distance that the short ties will not be required to sustain any portion of the weight, the effect of which is to provide a remedy at the expense of economy, by the introduction of from 15 to 30 feet of additional truss.

A bridge whose corresponding timbers in all its parts are of the same size, is badly proportioned; some parts must be unnecessarily strong or others too weak, and a useless profusion of material must be allowed, or the structure will be insufficient.

If, for example, the forces acting on the chords increase constantly from the ends to the centre, the most scientific mode of compensation would appear to be, to increase gradually the thickness of the chords; and, for similar reasons, the ties and braces should increase in an inverse order from the centre to the ends.

In accordance with this, it is found that in bridges that have settled to a considerable extent, the greatest deflection is always near the abutment; that is, the chords are bent more at this point than in the centre, and the joints of the braces are much more compressed. It is also found that the weakest point of a lattice bridge is near the centre of the lower chord; this might be expected, since, from the nature of the force and the mode of connection, the joints of the lower chords are only half as strong as the corresponding ones of the upper chord, it

* This calculation was made before the completion of the bridge: the correctness of the conclusions was soon confirmed: the pier began to crack after the opening of the road, and an increase of thickness by the addition of buttresses was found necessary.

being assumed that the resistances to compression and extension are equal. This defect may be in a great degree removed by inserting wedges behind the ends of the lower chords. A variation in the size of every timber, according to the pressure it is to sustain, would, of course, be inconvenient and expensive; but, as the principle of proportioning the parts to the forces acting upon them is of great importance, such other arrangements should be adopted as will secure its advantages, and at the same time possess sufficient simplicity for practice; this is effected by the introduction of arch-braces or arches, than which a more simple, scientific, and efficacious mode of strengthening a bridge could not perhaps be devised, as they not only serve, with the addition of straining-beams, to relieve the chords, and give them that increase of thickness at the points of maximum pressure which is essential to strength, but they also relieve the ties and braces by transmitting directly to the abutments or other fixed supports, a great part of the weight that they would otherwise be required to sustain.

It may, perhaps, be objected that the pressure of the arch-braces or arches would injure the abutments: in answer to this it may be remarked, that a certain degree of pressure is very proper; the embankment behind an abutment exerts a very great force upon it, the tendency of which is to push it forward. If, then, a counter-pressure can be produced by the thrust of arch-braces or by wedging behind the ends of the lower chords, two important advantages are gained; the abutment is not only increased in stability, but the tension on the lower chord of the bridge is diminished by an amount equal to the degree of pressure thus produced.

It is, however, proper to observe, that when the situation of the embankment exposes it to the danger of being washed away from the back of an abutment, the pressure on its face must not be sufficient to destroy its equilibrium; should this effect be apprehended, the horizontal ties must be sufficient to sustain the thrust of the bridge.

An essential condition in every good bridge is, that it shall not only be sufficient to resist the greatest dead weight that it can ever be required to sustain in the ordinary course of service, but it must also be secure against the effects of variable loads. This is generally effected by the addition of counter-braces; but the lattice truss possesses this peculiarity, that it is counterbraced without the addition of pieces designed exclusively for this purpose: to prove this, invert the truss, when it will be apparent that the braces become ties, and the ties braces, possessing the same strength in both positions.

Fig. 12 is the elevation, and *Figs.* 13 and 14 details of the improved lattice. The difference between this and the common lattice is—

1st. The braces, instead of being single, as in the common lattice, are in pairs, one on each side of the truss, between which a vertical tie passes; this arrangement increases the stiffness, upon the same principle that a hollow cylinder is more stiff than a solid one with the same quantity of material, and of the same length, and obviates the defect of warping.

2d. The tie is vertical, or perpendicular to the lower chord, a position which is more natural, and in which it is more efficacious than when inclined.

3d. The end-braces all rest on and radiate from the abutment, by which means a firm support is given to the structure, and the truss is not required of greater length than is sufficient to give the braces room.

4th. The truss is effectually counterbraced, the braces becoming ties, and the ties braces, when called into action by a variable load, and are capable of opposing a resistance on the principle of the inclined tie of the ordinary lattice bridge.

It is readily admitted that the strength in the inverted is less than in the erect position, but it must be remembered that the unloaded bridge is always in equilibrium; that the action of the parts which renders counterbracing necessary, results entirely from the variable load, and that, therefore, a combination of timbers to resist its effects should not be as strong as that which sustains both the permanent and the variable loads.

Behind the ends of the lower chords at the abutments, and between them over the piers, double wedges are driven, the object of which is, by the compression which they produce, to relieve the tension of the lower chord.

For ordinary spans, the dimensions of the timbers may be—

Braces	2 in. by 10 in. in pairs.
Ties	3 „ 12 „
Arches or arch-braces .	6 „ 12 „
Chords	3 „ 14 „ lapped.
Pins . . .	2¼ in. in diameter.

In conclusion, it is proper to remark that the proposed plan is not recommended as the best under all circumstances, but it is as economical in first cost as any other that can be used. The arrangement will be found even more simple than the ordinary lattice, and it is equally applicable for bridges on common roads or railroads, and for roof or deck bridges. The braces, in consequence of being placed in pairs, require a slight increase of timber over the common plan, in the proportion of 40 to 36, but the diminished lengths of the ties and of the truss more than counterbalance this increase.

The cost of workmanship on the truss is very trifling, and less than on the common lattice; if the timbers are cut to the proper lengths, the auger will be the only tool required in putting it together.

Plate LV., *Figs.* 1 to 6, illustrate the construction of a skew bridge erected over the Leith Branch Railway, Portobello, on the North British Railway.

This viaduct was formed of timber, principally on account of the ground being of a nature unfavourable to the construction of a stone bridge, and also owing to the very great angle at which the public road and Leith Branch Railway is crossed. To allow sufficient headway for the Leith Branch, it is spanned by cast-iron girders of an elliptical form, resting on a timber sole, so as to render struts unnecessary. The spans beyond the crossing of the road and railway for the remainder of the viaduct, are thrown on the square by a simple method which is shown on the plan.

The details of the structure are to a great extent delineated in the plate; it is therefore unnecessary to enter into them here.

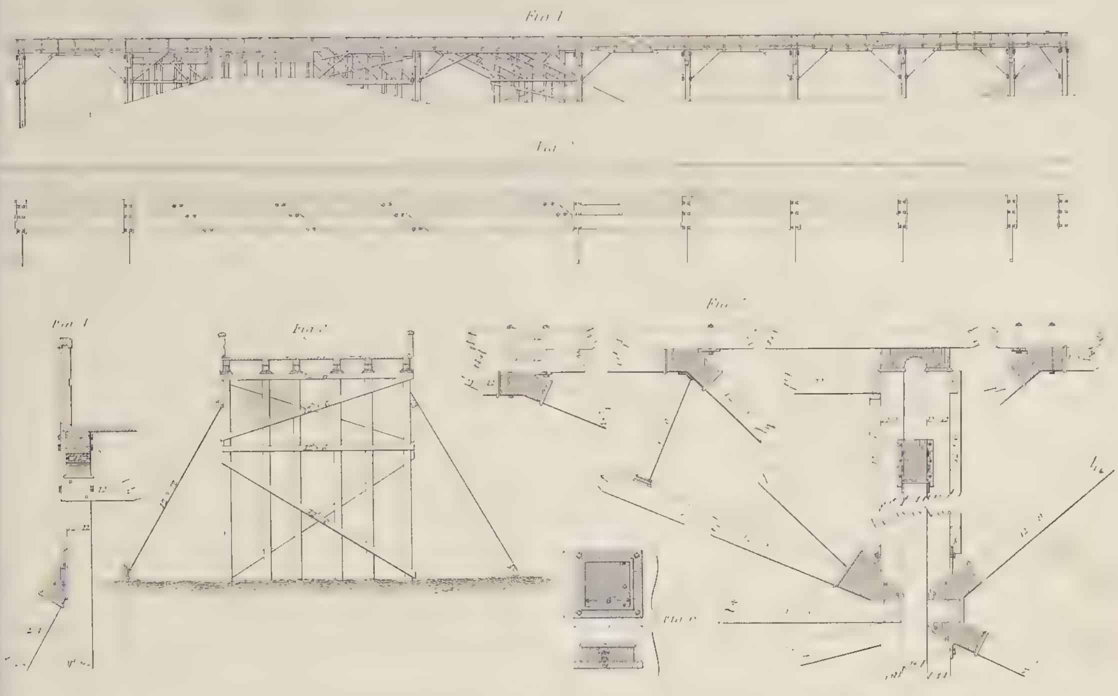
Fig. 1, the elevation of the bridge.

Fig. 2, the plan.

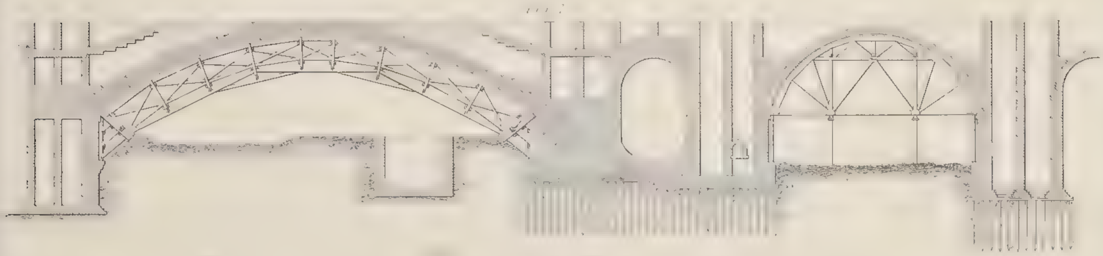
Fig. 3, a vertical transverse section.

BRIDGES AND CENTRES,

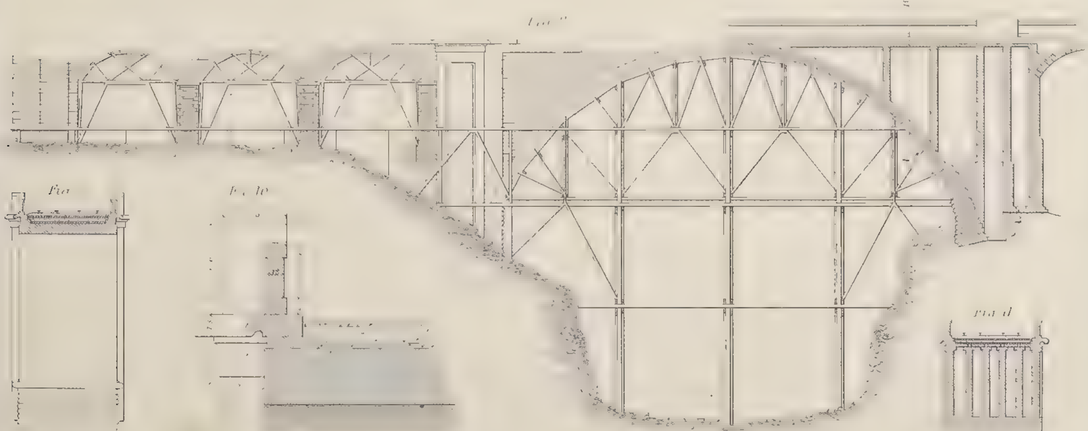
BY JOHN MILLER, C.E.



Elevation, Plan, and Details of Skew Bridge over the Leith Branch Railway &c. at Portobello, on the North British Railway.



Centring of Viaduct over the Union Canal near Falkirk on the Edinburgh and Glasgow Railway

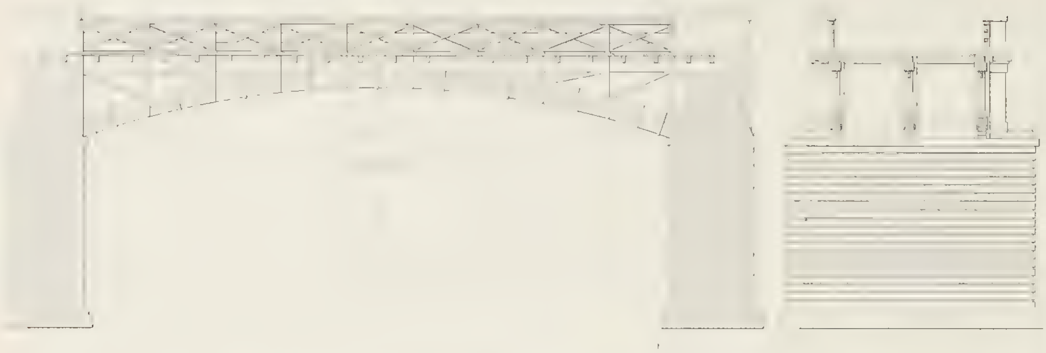


Centring of Viaduct over Dunglass Burn on the North British Railway

200 Feet

J. W. Lowry fc.

BLACKIE & SON GLASGOW EDINBURGH & LONDON



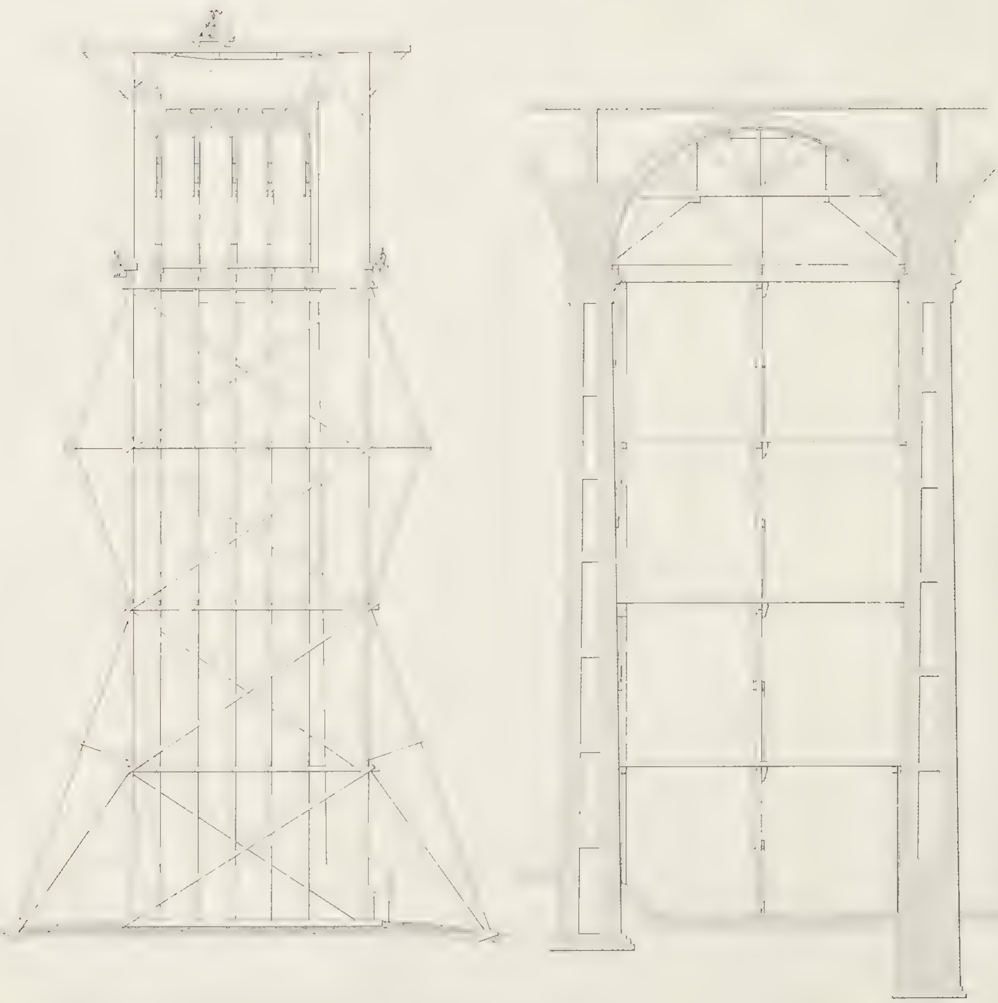


Fig. 4, a section to a larger scale, showing one of the trusses and rail.

Fig. 5, details to a larger scale of piers, chords, struts, waling pieces, and the iron work serving to unite them.

Fig. 6, the cast-iron capping of the pier piles.

Figs. 7 to 11 on this plate are described under the section CENTRES.

Plate LVI.—*Figs.* 1 and 2 illustrate a bridge of the third class, which is erected across the river Tweed at Mertoun.

This bridge consists of five arches, each 70 feet span, erected on stone abutments and piers. It was intended originally to be built entirely of stone, and although timber was adopted for the arches at the time of its erection, it was considered probable that stone arches might at some future time be substituted for the wooden framing. The piers and abutments were therefore made of such dimensions and strength as to be sufficient for stone arches. The work was commenced in 1839 and finished in 1841, by Mr. William Smith, contractor, Montrose.

The whole of the piers and abutments were built on rock, which was reached by means of cofferdams, and which was penetrated to the extent of from 1 to 3 feet, on purpose to get a solid and level foundation. The depth of the different foundations varies from 6 feet 3 inches to 11 feet 7 inches below the summer level of the river, and the height from the summer level to the springing of the arches is 18 feet. It was intended originally to make this only 16 feet, but in consequence of an unusually high flood occurring during the building of the piers, the height was increased 2 feet. The extreme length of the body of the piers in the plan is 29 feet 6 inches, and their thickness is 10 feet. The foundation extends 1 foot on every side beyond these dimensions, and is diminished to them by two footings of 6 inches each. The whole of the mason work is of freestone, obtained in the neighbourhood of the bridge.

Each arch consists of three laminated beams or ribs; each rib is formed of 5 thicknesses of half logs 12 × 6 inches, which were bent on a frame or centre, and fixed together, previous to their erection. The depth of the rib at the ends is 2 feet 6 inches, but in the centre it is diminished to 2 feet, the upper layer being cut horizontally to connect it with the longitudinal beam of the roadway. Each curved rib is bound together by eleven clasp hoops of iron, three of them embracing also the roadway beam; and the different layers of bent timber are kept from sliding on each other by oak keys, to the number of 60 in each rib, inserted horizontally, and sunk half their thickness into the contiguous layers. The longitudinal roadway beams are each 12 inches square, and connected with the curved rib by the iron straps above mentioned; also by the insertion between them of six upright braces 10 × 6 inches, and further by clamps 6 inches square, one on each side of the rib, halved upon the beams, so as to fit close on both beams and braces. The outward clamps of the external trusses extend upwards and form the posts of the parapet railing, and all the parts are securely fixed together by $\frac{5}{8}$-inch bolts. Between the upright ties, braces 12 × 6 inches are fitted, reaching from the curved rib to the horizontal beam. In each arch, the curved beams are connected by six cross ties, notched upon them, and stiffened by four pairs of diagonals, $4\frac{1}{2}$ inches square, all fixed by strong spikes.

The roadway is supported by cross-beams, 9 × 4 inches, placed 4 feet apart between centres, supported by the longitudinal beams, notched 1 inch upon them, and bolted down. On these, 3-inch planking is laid, and covered by wood sheathing $1\frac{1}{4}$ inch thick, crossing the planking obliquely, and having tarred paper interposed. Over this sheathing lies a coat of gravel, bedded in Archangel and coal-tar pitch to the thickness of 1 inch, forming a completely water-tight sole; covering this is a layer of stiff clay puddle 2 inches in depth, and over all a layer of common road metal, blinded with fine gravel and sand. The width of the roadway within the parapets is 18 feet.

The parapet railing is formed by posts 6 inches square, being the continuation of the ties of the arch trusses, secured to the roadway planking by iron stirrup straps, and tenoned at the top into a rail, 6 inches by 4 inches; the top rail is surmounted by a coping 7 inches broad, $1\frac{1}{2}$ inch thick in the middle, and 1 inch at the sides, and it is further secured by an iron strap at each post, passing over the top and down each side of the post, fixed with nails. Each compartment is fitted with braces and counter-braces, and a panel rail at bottom, 4 inches broad by $2\frac{1}{2}$ in depth, the former halved at their crossing, and tongued into the posts at head and foot, and the latter tenoned into the posts. Two lines of bars, 5 × 2 inches, run along the inner side of the railing, notched into and upon the posts each $\frac{1}{2}$ inch, and securely nailed both to the posts and to the diagonals. For descriptions of *Figs.* 3 and 4 on this plate, see *Centres.*

CENTRES.

Centres are works in carpentry which serve to sustain the masonry of vaults or arches during their construction, and until the insertion of the keystone gives them the power of sustaining themselves. Under this view centres are true scaffolds.

Centres are of different species, according to the nature of the curvature of the vault. The disposition of the timbers of which they are composed is analogous to that of timber bridges and of roofs, and the different elementary pieces are known by the same names. Each centre is composed of a series of frames placed parallel to each other, and perpendicular to the axis of the vault or arch. They are tied together horizontally, and covered with boarding, technically termed *lagging*, which forms the cradle or mould to support the masonry.

Centres are distinguished also by the mode in which they are constructed. Thus there are flexible centres, which may undergo a change of form during the construction of the vault, by the varying nature of the load. Of this kind was the centre of the bridge of Neuilly, constructed by Peronnet. There are also fixed centres, which maintain their form under the varying load, and these flexible and fixed centres may be either in one span supported only at the springing of the vaults, or they may be sustained by intermediate supports.

The flexible centre is composed of a series of triangular trusses, arranged so as to form concentric polygons, the angles of the one corresponding to the sides of the other. Hardouin Mansard has the reputation of being the inventor of this principle. It was applied by him in construct-

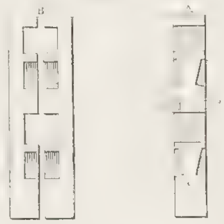
ing the centres for building the bridge of Moulins in 1706, but there is proof that it had been previously proposed by Claude Perrault for a wooden bridge designed to cross the Seine at Sevres.

In Plate LIX., *Fig.* 2, is shown Peronnet's centre for the bridge over the Seine at Neuilly, an example on the largest scale of this kind of centre.

The annexed diagram (Fig. 482) is a representation of the framing at A in the plate.

The flexibility of this system arises from the smallness of the angle of inclination between the timbers, and the number of articulations or joints on which the pieces can turn and change their inclination relatively to each other. The result is, that as soon as the centre is charged with the weight of the masonry on its haunches, it sinks there and rises at the crown. To remedy this grave inconvenience, which is attended by a complete change in the form of the vault, and may result in serious accidents, it is necessary to load the crown of the centre with such a weight as shall equilibriate the load on the haunch, and to vary this as the work proceeds, so as to maintain the integral form. In practice this equilibriating load is really the voussoirs which are laid temporarily in their place before being properly set, a process involving a great expense of labour and a continual manipulation, attended by considerable risk.

Fig. 482.



The sinking of the haunches and rising of the crown were so great in the centres of the bridge at Neuilly, that to restore them to their primitive form, and to enable them to retain it during the construction of the arch, it was found necessary to load their summits successively with weights of 120, 420, and 448 tons. When the arches were keyed, the general sinking of the centres amounted to from 2·75 inches to 3·15 inches in twenty-four hours. When the centres were struck the arch descended.

It is not necessary to enlarge further the notice of the species of centre which has been classed as the flexible centre, as in this country it is entirely unknown; and although it was used in some magnificent works, and its use was sanctioned by the high authority of Peronnet, yet it is now abandoned in France also.

The second class, which has been termed the fixed or inflexible centre, is that which has alone been used in this country, which has produced examples exhibiting a happy combination of science and constructive skill. It may well be supposed that the art of disposing the pieces of timbers, which enter into the composition of a centre, in such a manner that they may sustain, without change of form, all the efforts of the voussoirs, varying with the progress of the work until the key-stone is placed, and to determine the dimensions of the timber, is not of easy attainment.

The theories which the learned have given to the world on the subject of centres are so general, as to be totally inapplicable to particular cases; and they are founded besides on abstract reasoning, without reference to the materials, and those means and appliances of the workmen which sometimes totally change the state of the question and always modify the results. Unless, indeed, the design of the framing of a centre be of a very simple nature, it would be very difficult to attempt to estimate the forces and the strengths required to sustain them. The best that can be done is only approximative, and no more is attempted in the rules which are subsequently given.

The result of investigations on the pressure of arch-stones on a centre is, that the centre should be combined in such a manner as to withstand as advantageously as possible the effort of the stones to slide upon their beds.

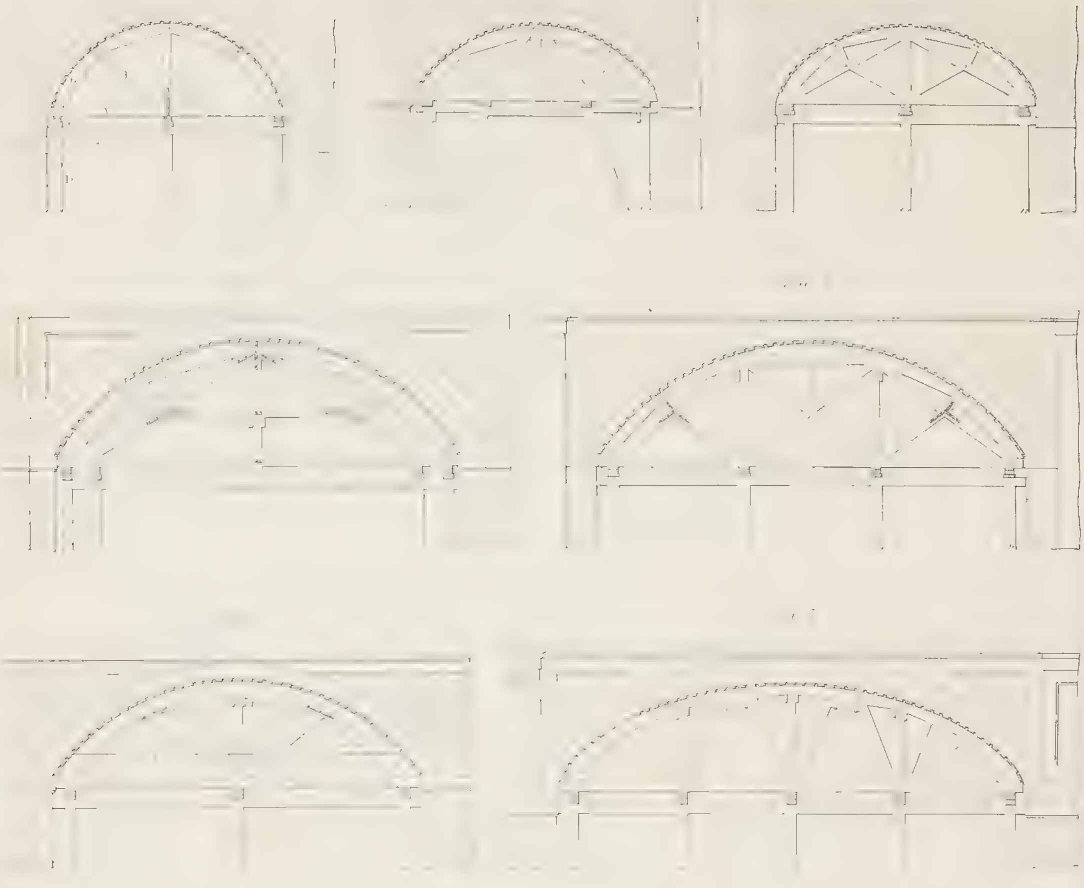
Experiment has shown that hard stones have not any tendency to slide on the bed until it is elevated to about 30°; and it has also shown that when the stone is set in fresh mortar it does not begin to slide until the bed is elevated to an angle of from 34° to 36°. Voussoirs of soft stone, absorbent of moisture, have been raised to an angle of 45° without sliding, when the centre of gravity did not fall without their base.

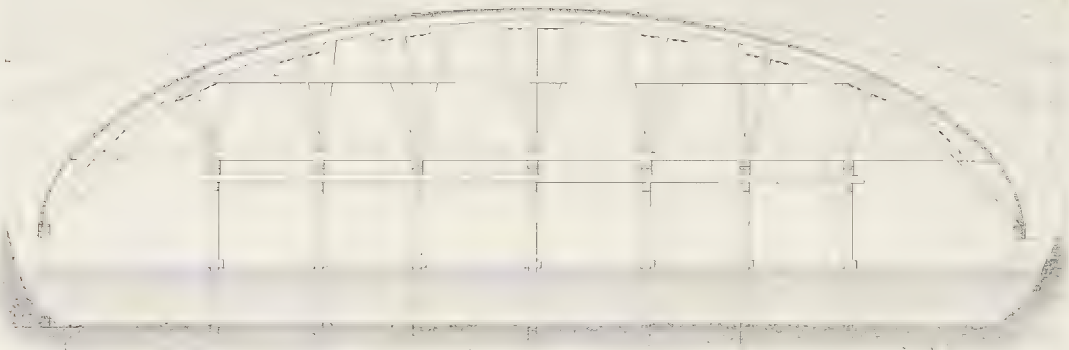
Reasoning from these experiments, and assuming 32° as the limiting angle of resistance, the conclusion would be arrived at, that the centre did not require to commence until the arch stones had reached that angle; and in the Pont du Gard and the arch of Cestius at Rome, the corbels on which the centres were supported remain at from 25° to 28° above the springing.

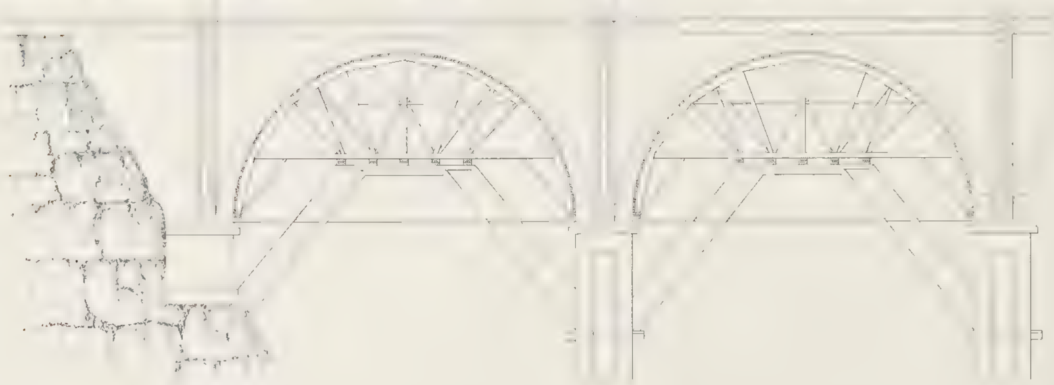
Beyond 32° the weight on the centre goes on increasing as it approaches the key-stone; but in practice it is safe to consider the whole weight of the stone as resting on the centre, when a vertical line drawn through its centre of gravity falls without the lower bed of the stone; and the amount of error is not great, and is on the safe side, if this is taken to be the case when the bed of the stone exceeds 60°. But to make this observation more accurate, we quote Mr. Tredgold's words. He says, "When the depth of the arch stone is nearly double its thickness, the whole of its weight may be considered to rest upon the centre, at the joint which makes an angle of about 60° with the horizon. If the length be less than twice the thickness, it may be considered to rest wholly upon the centre when the angle is below 60°, and if the length exceed twice the thickness, the angle will be considerably above 60° before the whole weight will press on the centre."

To find the pressure of the arch stones on the centre, in a direction perpendicular to its curve, Mr. Tredgold has given the following formula:—$W(\sin a - f \cos. a) = P$. Where W is the weight of the stone, P the pressure on the centre, $a =$ the angle which the lower bed makes with the horizon, and $f =$ the fraction; and by applying this formula he obtains the following result:—

When the bed makes, with the horizon, an angle of	the pressure = the weight, multiplied by
34°	·04
36	·08
38	·12
40	·17
42	·21
44	·25
46	·29
48	·33
50	·37
52	·40
54	·44
56	·48
58	·52
60	·54







Centring of Cartland Crags Bridge

The application of this may be illustrated by an example. Suppose it was required to find the pressure of the arch-stones on the centre, in a space comprehended between the angles of 32° and 42°, that is in 10°, take out of the preceding table the decimal opposite every second degree, for the first 10°, and add them together as follows:—

$$\left.\begin{array}{l}\cdot04\\ \cdot08\\ \cdot12\\ \cdot17\\ \cdot21\end{array}\right\} = \cdot62$$

Multiply this number by the weight of a portion of the arch stones comprehended between two degrees, and the product will be the pressure on the centre.

Suppose the centres to be 6 feet apart from outside to outside, and the depth of the arch stones to be 8 feet, as in Waterloo Bridge, and the space comprehended between two degrees, measured at the middle of the depth of the stone, is 2 feet, there is obtained—

6 feet = the distance betwixt the centres.
8 feet = depth of the arch stones.
2 feet = width of the portion sought.

$6 \times 8 \times 2 = 96$ cubic feet, which, multiplied by 160 lbs. the weight of a cubic foot of stone, = 15,360 lbs., the weight of two degrees; and this, multiplied by ·62, gives 9523 lbs. for the pressure of 10° of the arch stones on one centre frame.

The pressure on the centre, it has been said, may be considered equal to the whole weight of the stone, from 60° to 90°, and from 60° to the angle of repose the pressure rapidly diminishes. It would be manifestly erroneous, therefore, to make the frame of the centre equally strong throughout; and the endeavour in designing it should be to apply the strength only where it is really required. How this has been managed by different designers will be seen by examining the drawings of examples of centres in Plates L., LV., LVI., LVII., LVIII., and LIX.

In designing centres, the observation which Mr. Smeaton makes on his own design for the centering of Coldstream Bridge may be held to be a sound practical maxim. "What I had therefore in view," he says, "was to distribute the supporters equally under the burden, preserving at the same time such a geometrical connection throughout the whole, that if any one pile or row of piles should settle, the incumbent weight would be supported by the rest. With respect to the scantlings, I did not so much contrive how to do with the least quantity of timber, as how to cut it with the least waste; for as I took it for granted the centre would be constructed with east country fir, I have set down the scantlings, such as they usually are, in whole baulks, or cut in two lengthways; and as I think the pieces will suffer less by notchings in the middle intersection, and being cut into small pieces, it will remain of value for common building after it has been done with as a centre." And he adds in favour of simplicity, "As the construction is more obvious, and less exactness required in the handling, I should expect to get a good centre made by some in this way that would make but bad work of the other."

Fig. 1, Plate LVII., shows a centre for a small span. It consists of a trussed frame, of which A is the tie, B the principal, or, as its outer edge is curved to the contour of the arch, it is called by Mr. Smeaton the *felloe*, C the post or puncheon, and F a strut. The centre is carried by the piles D, on the top of which is a capping piece E, extending across the opening; and the wedge blocks *a* are interposed betwixt it and the tie-beam.

Figs. 2 and 3 are centres, also for small spans; and of this *Fig.* 2 is the best in its arrangement.

In *Fig.* 4 the weight of the centre of the arch is carried directly by the struts to the ends of the tie-beam, the tie-beam struts and king-post A making a simple king-post truss. Two other trusses support the arch above the haunches, and have a collar-piece between them at half the height of the arch. The ends of the cross-braces are seen at *a*.

Fig. 5 shows a centre with intermediate supports and simple framing, consisting of two trusses formed on the puncheons over the intermediate supports as king-posts, and subsidiary trusses for the haunches, with struts from their centres parallel to the main struts.

In *Fig.* 6 the weight is fairly distributed between the three points of support. The ends of transverse braces connecting the trusses are seen at *a*.

Fig. 7 shows a system of supporting the arch rib from the intermediate supports by radiating struts, which, with modifications to suit the circumstances of the cases, has been very extensively adopted in many large works, and of which other examples are here presented. The struts abut at their upper end on straining pieces, or apron pieces, as they are sometimes termed, which are bolted to the rib, and serve to strengthen it. The ends of the transverse braces are seen at *a a*.

Fig. 8 is the centre of a bridge over the river Don, in Aberdeenshire. The bridge consists of five arches, each of 75 feet span. It was erected from designs of Thomas Telford, Esq., by Messrs. John Gibb & Son, of Aberdeen, who designed the centres.

In this centre the weight is in a very simple and ingenious manner discharged to the points of support. The piles are cross-braced; the sides of the braces are seen at *d c*; and the puncheons above are also connected by a system of cross-bracing, *b b*.

Plate LVIII., *Fig.* 1.—*Centering of Gloucester Over-bridge.*—This centre, designed and constructed by Mr. Cargill, the contractor for building the bridge, consists of a series of trusses supported on piles, which being in some cases 16 feet apart, allowed the navigation to be carried on.

There are six parallel rows of piles fixed in the current of the river, each row connected with cross-braces and caps, and each supporting a rib, which forms the actual centering. The piles and ribs are further steadied by diagonal braces. Between the pile caps and the ribs are placed the wedges or slack-blocks by which the centering is lowered after the keying of the masonry.

Mr. Cargill, in a letter to Mr. Telford, dated March 26, 1832, thus describes the construction of the centre:—

"In constructing the centering for this bridge, I first laid a platform perfectly level, and a little larger than the centering which was to be made; I then struck it out full size upon this platform, firmly fixing centres to the different radii. The timber was Dantzic, being much harder and of larger dimensions than Memel, and mostly 15 inches square. The iron straps were of the best iron.

"The piles upon which the centre was to stand were then driven. They were of Memel timber, with wrought

iron shoes, and caps framed upon the tops to the proper height. Upon these caps was laid another tier of beams lengthways of the centre one, under each rib; upon these beams were fixed the wedges, which were of three thicknesses, the bottom one being bolted down to these beams, the tongue or driving piece in the middle being of oak, and well hooped at the driving end; the top side of the upper piece was laid perfectly level and straight, both transversely and longitudinally. The wedges were rubbed with soft soap and black lead before they were laid on each other.

"Each rib of the centre was then brought and put together upon a scaffold made on the tops of these wedge-pieces, and lifted up whole by means of two barges in the river and two cranes on the shore. The scaffold was extended thirty feet beyond the striking end of the wedges, to lay the last ribs upon previous to raising, also to stand upon for finally striking. After the ribs were properly braced, they were covered with 4-inch sheeting piles, which had been used in the cofferdams.

"That this centre was well suited to its purpose is known by its not sinking more than one inch when we keyed the arch. My greatest dread was the coal-boats which trade on the Ledbury Canal, forced adrift by floods in the Severn, and striking against the centre before we could close the arch. To prevent mischief of this kind, I drove the piles for extending the up-stream side of the scaffold (or rather the platform on which it was originally constructed) very firmly into the clay, so that they might resist the stroke of a boat before she could touch any of the supports of the centering.

"In the month of December, when within twenty feet of closing the arch, a very high flood being in the Severn, two of these boats loaded with coal came adrift, struck the outside piles, which were of Memel logs, broke two of them, and then sank against the main bearing piles which supported the centre, one boat on the top of the other. These boats being seventy feet long, raised a considerable head of water over them, and lay there until the flood subsided, which was many weeks; had not these upper guard piles weakened the shock, I believe the whole centre and arch would have been destroyed.

"When the spandrel walls were built up two courses below the crown of the arch, and the internal brick walls to the same height, we struck the centre, which was done by placing beams upon the top of the work directly over the ends of the wedges. To these beams successively was fixed a tackle, to which, at the lower end, was slung the heavy ram with which we drove the piles, with tail ropes to it, and swung exactly so as to strike, in its swinging, when pulled back, the driving end of the tongue piece of the wedge. This ram, of 12 cwt., when pulled back by eight men, and two men to pull it forward, gave a most tremendous blow, yet twenty or thirty blows were requisite before we could perceive the wedges to move; but after they once moved, they slid themselves, and we put in pieces to stop them going further than was required. The whole time of striking did not, I think, exceed three hours, although we had the ram to remove and the tackle to refix at every set of wedges. I was afraid that no force we could bring against these wedges would move them under such a weight as the entire arch, they themselves being a heavy body, and it was no small joy to see this effected so easily. I am persuaded no wedges placed in the usual way could have been disengaged, as no force could be brought to act upon them sufficient for the purpose.

"We then disengaged the covering (which, it will be remembered, was composed of sheeting piles from the cofferdam), and let down the ribs as they were put up; took them to pieces and carried them ashore. The whole of the bearing piles were then drawn by two levers, each made of two forty-feet logs and strong chains. Every pile was drawn, and although the expense was considerable, they paid well for the labour."

Fig. 2.—The Centering of Dean Bridge, Edinburgh, constructed by Telford, in 1831.—The height from the bed of the river to the roadway of this bridge is 106 feet, and the bridge consists of four arches, each of 90 feet span. The carriage way is carried on the inner arch, and the larger wing arch, which projects 5 feet beyond the other, supports the footpath. No. 1 shows the centering for this latter arch, and No. 2 the centering for the main arch.

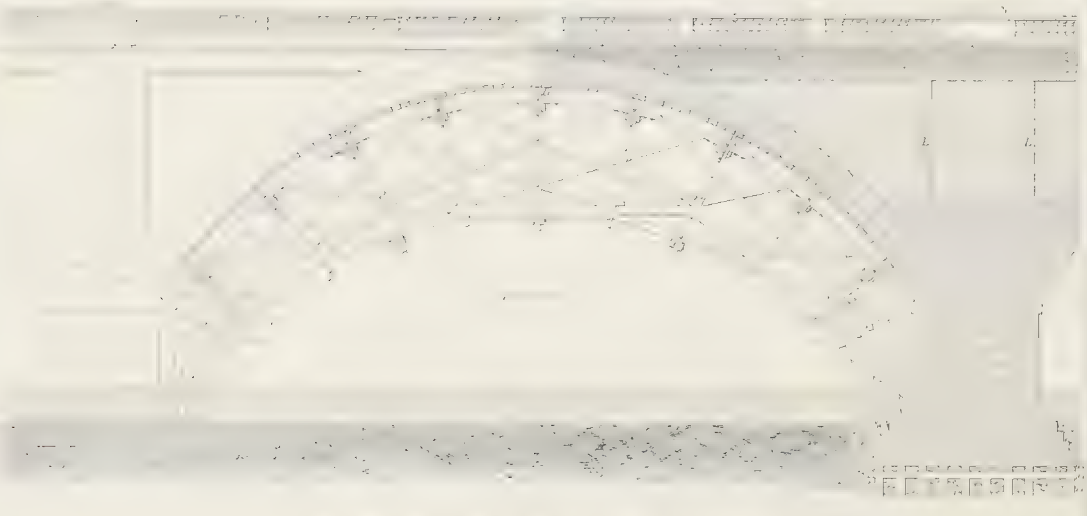
Fig. 3.—The Centering of Cartland Craigs Bridge is here represented.—Cartland Craigs Bridge, built by Telford, in 1821, spans the precipitous banks of the Mouse River. It consists of three arches, each of 52 feet span, and the centre arch is 122 feet in height.

PLATE L.—*Figs.* 6, 7, 8, 9, and 10, in this plate, illustrate the construction of the centering used in constructing the Ballochmyle Viaduct on the Glasgow and South-Western Railway.

The river Ayr, which the viaduct spans by an arch of 180 feet, offers natural facilities for crossing it by one span, owing to its high and rocky banks. This viaduct is erected on private grounds of great beauty, rendered classic by the song of Burns, and the railway company were bound not to interfere further than was actually necessary with the natural beauties of the river and its banks. With the view of carrying out that arrangement, the viaduct, as represented in the plate, was designed and constructed.

The main arch of this viaduct, which is semicircular, has a span of 180 feet, and is in height, from the bed of the river to the crown of the arch, about 160 feet. It was therefore necessary to construct scaffolding and centering of no ordinary description. The principle on which this was done is new and simple. It was executed as much as possible with whole timbers, of which the uprights consisted, and where the distance of the points of thrust of the frame was not great, the struts and walings were of half timbers; the lagging consisted of battens. It will be seen from the representation in Plate L., and more distinctly in the picturesque view taken during the operations, and which forms the engraved title to this work, that the materials for constructing the viaduct were conveyed along by large waggons on a stage projected from the centering, and from them removed by travelling cranes moving longitudinally and transversely. The details of construction of this stage, and the general arrangement of the centering, do not call for special remark. It may, however, be necessary to add, that the whole timber work in connection with the construction of this viaduct perfectly answered the purpose.

PLATE LV.—*Fig.* 7, in this plate, is the centering of viaduct over the Union Canal, near Falkirk, on the Edinburgh and Glasgow Railway.



The reason for constructing this large arch over the canal, and the description of centering shown in the plate, was to meet the requirements of a clause in the railway company's act, by which certain heights and widths were to be preserved over the footway, carriage-way, towing-path, and canal, and no piers were allowed to be placed in the space between the abutments of the large arch, even for temporary purposes. The figure in the plate shows the principle on which the centering was constructed and kept in its position. The centering shown on the smaller arch of this viaduct does not call for any particular remark. Both were constructed so as to be simply and easily put together, using whole timber, so as to prevent waste.

Figs. 8 to 11, also in Plate LV., illustrate the construction of centres for the viaduct of the North British Railway, carried over Dunglass Burn. The span of the large arch is 132 feet, and its height 110 feet.

The principle of construction is nearly that of Ballochmyle Viaduct, already described. The smaller land arches, however, show a variation in the construction.

Plate LVI., *Figs.* 3 and 4.—*Fig.* 3 is a longitudinal, and *Fig.* 4 a transverse section of one of the arches of a viaduct, illustrating the mode of constructing and supporting the centering. The viaduct was erected over the Lugar Water, near Old Cumnock, in 1849, by J. Miller, Esq., C.E.

The supporting framing consists of four sets of horizontal timbers, sustained at their ends either by corbels in the piers, or by vertical timbers carried up from the ground, and resting at their centre on the capping-pieces of the series of seven vertical posts, seen in *Fig.* 4. These vertical posts rest on a sleeper below, and are firmly braced, counter-braced, and shored to give lateral stiffness. The two exterior posts carry the scaffolding used in the construction of the arch, and each of the five interior posts is placed under the middle of a centre.

The upper horizontal timber supported by the posts carries the centre striking wedges, and the two extreme wedges are carried by the impost of the piers. On these wedges the tie-beams of the centres rest.

Plate LIX.—*Fig.* 1 is the centre used in the construction of Waterloo Bridge.

Fig. 2.—The centre used in the construction of the elegant bridge over the river Seine at Neuilly, and already noticed in the introductory portion of this section.

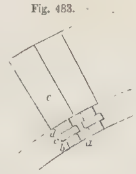
Fig. 3.—A design by Mr. White. Centre for a segmental arch of 120 feet span, somewhat after the manner of the centre for Waterloo Bridge. A C B C A are the felloes or arch of the centre, on which the lagging rests. To these are bolted the abutment-pieces *d d* of the struts *a a a a*, and the lower ends of the struts rest on iron sole-plates on the tops of the upper striking wedges F F. The radial posts F F F are in pairs, one on each side of the struts *a a*; they are bolted together, and secured to the felloes by iron straps: *c c* are transverse ties in pairs, bolted together through the radial posts: *h h* additional transverse ties, *k* principal tie, and *b b* straining pieces. D D F F are striking wedges; *e e e f* struts resting on sleepers laid on the footings of the piers, and having capping-pieces *g g*, on which the striking wedges rest.

On Removing Centres.

The removal of the centres of a bridge when loaded with the weight of the arch stones is always a delicate operation, demanding prudence and patience. It is necessary to allow sufficient time for the setting of the mortar used in the construction of the arch. It may be conceived that unless this is done, and if the centres are *struck*, as it is termed, before the mortar acquires proper consistency to resist the pressure thrown on it, there would be a sudden sinking of the whole arch, which might pass the limits of safety.

In the bridge of Nemours, in France, the arches of which were surbased, the pressure on the centres was found to be so great that the usual mode adopted in France for the striking of the centres could not be followed. The mode of supporting the arch stones on the centres there adopted was somewhat different from the practice of this country. In place of a continuous covering of boards, which is here called lagging, the bridge in question had the following contrivance (Fig. 483):

Fig. 483.



a is part of the centre; on this is placed the wedge-piece *b*, supporting the plank *c*, which continues across the arch, there being one for every course of voussoirs. The voussoir *e* is supported on *c* by the wedge-piece *d*.

The striking the centres should have been performed by withdrawing the wedge-pieces *b* and *d* of every alternate plank, and then the plank *c*, and then repeating the operation, leaving a fourth-part remaining, and so on till all were withdrawn; but, as has been said, this could not be done, and recourse was had to the expedient of cutting away gradually the feet of the principals, which rested on the corbels of the abutments—a mode clumsy in the extreme, and also dangerous.

The method of striking the centres practised in this country is preferable in every respect to the French mode. That usually adopted is seen in Plate LIX. *Figs.* 1 and 3. In *Fig.* 3 it will be seen that each centre frame is supported on posts *e e e*, springing from the footings of the pier. These posts have capping-pieces, *g g*, extending across the whole width of the arch. Between the capping-pieces and the frame are interposed three pieces of timber, the two outer of which, F F, have their inner faces stepped in wedge-shaped surfaces, and the intermediate piece, D D, is doubly stepped in the same way to correspond. If the position which these pieces relatively hold is remarked, it will be seen that when the piece D is driven back towards the arch, the two pieces F will approach each other, and the centre will thus be gently lowered. A great advantage is the power that this mode gives of merely easing the centre first, and then lowering it by degrees, so that the voussoirs come gently to their bearing.

A method of striking the centre, closely resembling the French method described above, was practised at the Chester Bridge. Each centre frame there had a rim of two thicknesses of 4-inch plank bent round it; and on this the lagging, $4\frac{1}{2}$ inch thick, was supported by a pair of folding wedges, 15 or 16 inches long, 10 or 12 inches broad, and tapering about $1\frac{1}{2}$ inch. As there were six centre frames in the width of the bridge there were necessarily six pairs of striking wedges for each course of voussoirs. This arrangement gave the power of easing any portion of the arch, or of tightening one part and slacken-

ing another, as the symptoms exhibited by the stone work as it came to its bearing required. The able constructor of this centre, with the power which this mode of construction gave him, preferred striking the centre while the mortar of the arch-stones was yet green and pasty, easing it a little at first to permit the joints to accommodate themselves to each other, and so proceeding gradually till they obtained their perfect bearing.

A different method was employed by the constructor of the centre for Gloucester Bridge. In this centre the wedges were placed under all the supports, and in this way a very great control over its movements could be exercised. A similar arrangement was adopted by Mr. Telford in many of his larger works, as in the Dean Bridge and Cartland Craigs Bridge, Plate LVIII.

GATES.

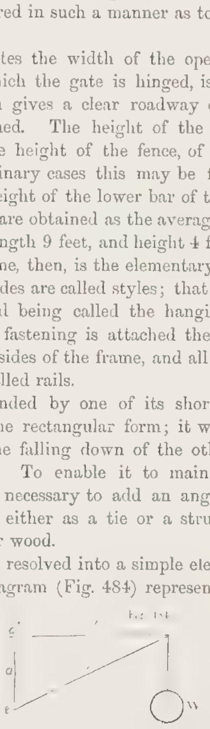
A gate, in its ordinary acceptation, may be regarded as a moveable portion of a fence or inclosure; and under this aspect its most obvious representative is a rectangular plane of wood or iron, a door, in point of fact, and this is one of the forms it usually assumes. But in many cases such a gate would be objectionable on account of its weight and costliness; and there is, therefore, substituted for the rectangular plane of wood a rectangular frame of wood or iron, sparred or barred in such a manner as to prevent the passage of animals.

In ordinary field-gates the width of the opening between the posts, to which the gate is hinged, is usually 9 feet 8 inches, which gives a clear roadway of 9 feet when the gate is opened. The height of the gate depends, of course, on the height of the fence, of which it forms a part. In ordinary cases this may be five feet, and allowing for the height of the lower bar of the frame from the ground, there are obtained as the average dimensions of a field-gate—length 9 feet, and height 4 feet.

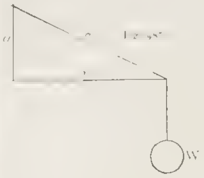
This rectangular frame, then, is the elementary form of the gate. Its vertical sides are called styles; that to which the hinges are attached being called the hanging-style, and that to which the fastening is attached the falling-style. The horizontal sides of the frame, and all the bars parallel to them, are called rails.

Such a frame suspended by one of its shorter sides would not maintain the rectangular form; it would become rhomboidal by the falling down of the other sides by their own weight. To enable it to maintain the rectangular form it is necessary to add an angle brace, which may be applied either as a tie or a strut, as the material used is iron or wood.

But the gate may be resolved into a simple elementary form thus:—Let the diagram (Fig. 484) represent—*a* the hanging-style, *b* the top-rail, and *c* the brace or strut of a gate, all firmly united. This is evidently a simple truss, like the

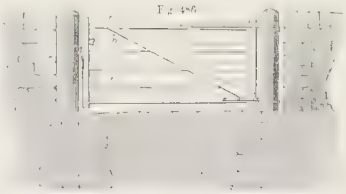


jib of a crane; and if a weight W be hung to its outer end, the rail *b* will obviously be in a state of tension, and the brace *c* in a state of compression; that is, *b* is a tie, and *c* is a strut. Again, let *a* (Fig. 485) be the hanging-style, *b* the lower rail, and *c* the brace, and it is now obvious that *c* is a tie and *b* is a strut. Therefore, keeping in mind the constructing maxim that iron should be used as a tie and wood as a strut, when the brace is



placed as in Fig. 484 it should be of timber, and when as in Fig. 485 it should be of iron. But it may be objected that, if this rule were adhered to, it would not be possible to construct a timber gate, as it requires both ties and struts. Now, the pieces of wood of which a gate is formed are framed together, and held in their places by bolts, nails, or wooden pins, and the frame is hung to the posts by iron hinges. The straps by which these hinges are attached to the frame are generally so long as to embrace a considerable portion of the length of the rail, and may, therefore, be made subservient to rendering the timber rail *b* (Fig. 484) competent as a tie; whereas if timber be used for the brace *c*, as in Fig. 485, it is evident that the strength of the brace has very little to do with the stability of the framing; that, in point of fact, the stability is due entirely to the strength of the nails, or to the slight resistance to tearing that the fibres of the timber between where the nails are driven and the end of the brace offer; or it must be insured by adding an iron strap to each end of the brace. But this extra iron is expensive; and as by simply making the brace a strut in place of a tie, the iron strap of the upper hinge can be made to supplement the deficiency of the upper wooden rail as a tie.

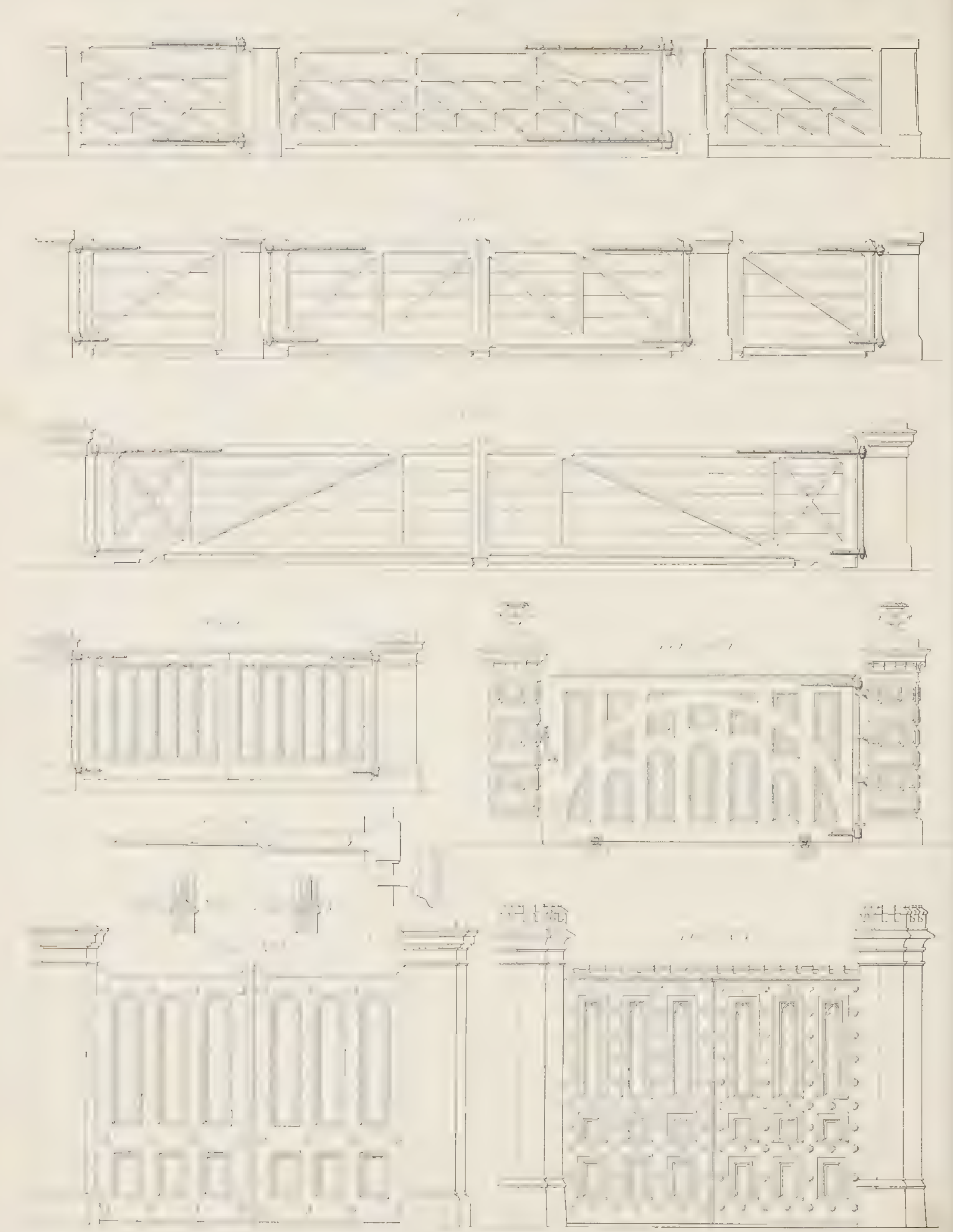
Fig. 486 is the ordinary field gate, constructed on the principles above described. The top rail *a* becomes a



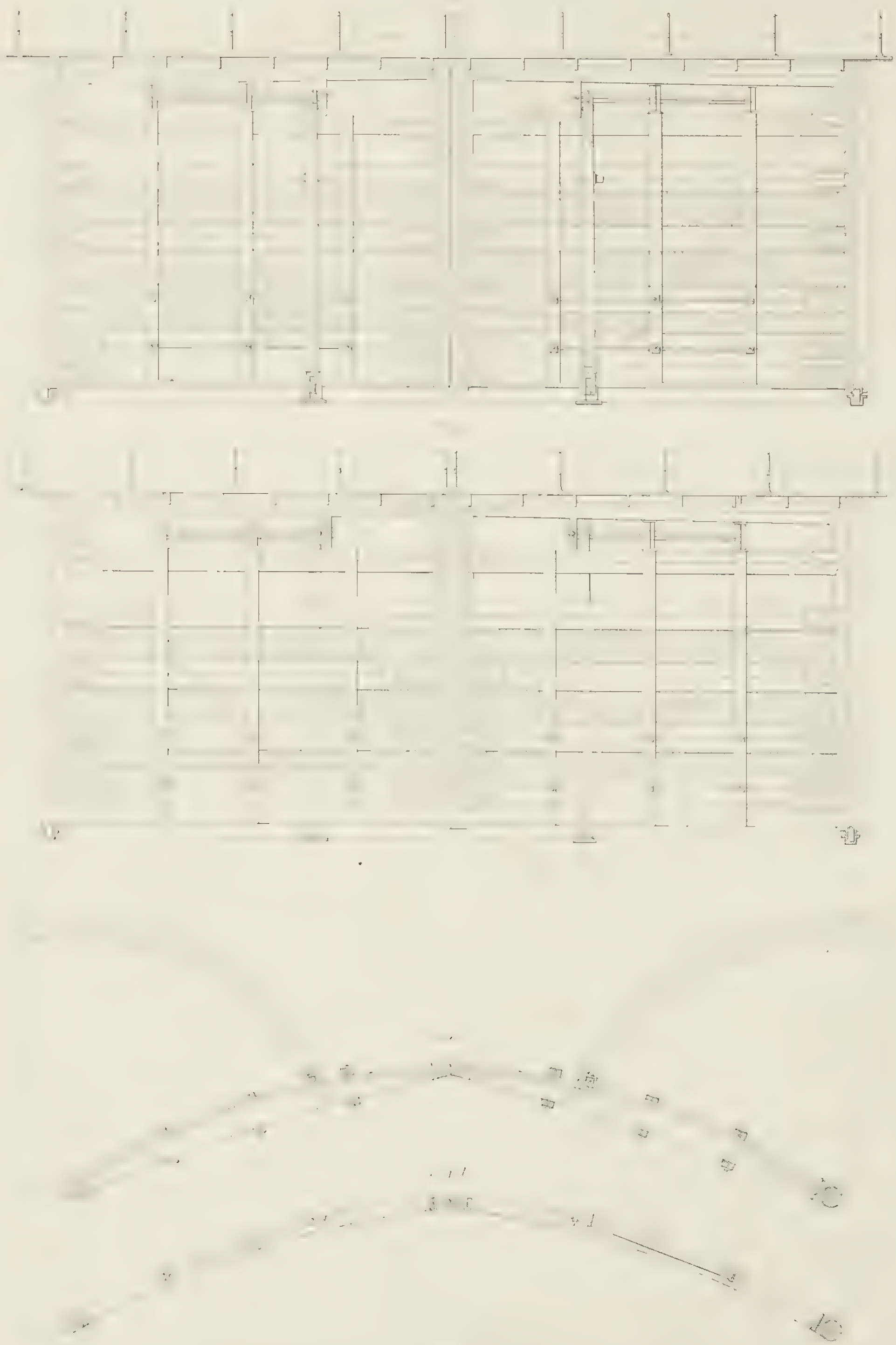
tie, and is secured to the hanging post by the strap of the upper hinge embracing it, and being bolted through it. The elementary frame is thus rendered perfectly rigid, and the addition of the front or falling-post *b*, and the bars *e*, *f*, *g*, *h*, completes the fence. By this mode of construction the tensile strain is thrown on the bolts and strap of the upper hinge.

Having thus pointed out the principle of stability in the framing of the gate, we shall proceed to give some practical details, showing its application to frames of wood and iron. In a timber gate, then, the diagonal bar should form a strut, as in Fig. 485, and not a tie. Were we merely to consider, in the application of the diagonal bar, the angle which should be the best fitted to insure the frame maintaining its form, we should adopt the angle of 45°. But the bar placed at this angle would not extend half-way along the top rail, and the result would be the introduction of a new element of destruction in the cross-strain, to which the top bar would then be exposed; for the point of the strut would be a rigid fulcrum, over which the top bar would be liable to be broken, by a

GATE

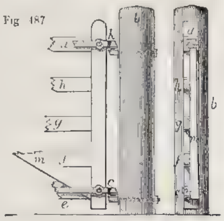


GATES.



weight hung to its outer end. Practically, therefore, it is better that the strut should make a smaller angle with the horizon; that in fact it should be attached to the top bar, at just such a distance from the end of the latter as shall not so much weaken it, as to prevent it forming a perfect abutment to the thrust of the strut; and, in ordinary cases, ten inches or a foot is sufficient. The junction of the strut and top rail should be by the same kind of joint as that by which the toe of a rafter is let into the tie-beam. Fig. 486 shows the general appearance; and Fig. 487 some of the constructive details of a gate, of the construction here advocated. The hanging-style of the gate is $4\frac{1}{2}$ inches square in section; the falling-style is 3 inches square. The top rail a is $4\frac{1}{2}$ inches square at the hanging style; and 3 inches by $4\frac{1}{2}$ at the falling-style. It is tenoned into the styles. The diagonal bar m is $4\frac{1}{2}$ inches deep, and 2 inches thick; tapering to the upper end for the sake of lightness. It is tenoned into the hanging-style, and notched into the top rail. The other rails e, f, g, h, are $4\frac{1}{2}$ inches deep at the hanging-style, and taper to $3\frac{1}{2}$ inches deep at the falling-style. They are $1\frac{1}{2}$ inch thick, and are tenoned into the styles, the tenons having only one shoulder on the outside, so as to allow of larger cheeks to the mortises in the styles. In Fig. 487, b is a vertical section through the rails and diagonal, looking towards the hanging-style. The upper hinge has its straps prolonged, as seen in Fig. 486, so as to embrace a considerable portion of the top rail, that the bolts and nails which fasten it may have a secure hold in the solid wood. The under hinge does not require this prolongation of the straps, as the force upon it is a thrusting, and not a drawing force.

Fig 487



As the bottom rail is so much thinner than the hanging-style, a small piece of wood, of the depth of the rail, is generally added at e, Fig. 487, as a rest for the strap of the hinge. The tenons of the rails are secured in the mortises by pins, and the diagonal is securely nailed to the rails at its intersection with them. Before putting the parts together, the tenons and the intersecting parts of the rails and diagonals should be coated with white lead in oil. The great destroyer of the gate is rain, which falling on the thin top bar, as usually constructed, soaks into the joints and induces rot. The wide top rail in the gate described, affords protection against this; and the only parts exposed to it are the intersections of the diagonal and rails; but, by giving the upper edges of these a slight bevel, so as to throw the water from the joint, the risk of injury from this cause is destroyed. The top rail should be saddle-backed, or rounded on the top. Sometimes vertical bars are added to the gate; but these, as we have already said, add to its weight, and not to its strength; and, moreover, introduce new joints, exposed to the action of the rain, and they should therefore be dispensed with.

Plate LX.—*Park and Entrance Gates.*—*Figs.* 1, 2, and 3 are examples of park gates, of open frames. *Figs.* 4, 5, 6 and 7 are elevations of entrance gates in various styles.

In *Fig.* 5, No. 1, it will be observed that two small rollers are inserted in the bottom rail of the gate, and run on iron rails, laid on stone sleepers fixed in the ground. The hinge-pin, too, is continuous between the top and bottom hinge, and serves merely as an axis on which the gate rotates, the whole of the weight being sustained by the rollers. It has sufficient play to allow the gate to rise as it opens. *Fig.* 5, No. 2, is the strap of the top hinge, and the same construction of strap is applicable to all the previous examples, where the object is to extend the hold of the strap on the top rail. The strap of the bottom hinge may in all cases be very short, and not as in *Fig.* 1, where for uniformity's sake it is extended to the same length as the upper strap.

Fig. 6, No. 2, is a section through the upper part of the lower rail of *Fig.* 6, No. 1; and *Fig.* 7, No. 2, a section through the rail of *Fig.* 7, No. 1. Both of them show that at the lower side of the panel the moulding is substituted by a splay or weathering to throw off the water.

Plate LXI.—*Dock Gates.*—*Fig.* 1 is an elevation of the convex side of one of the gates of the Coburg Dock, Liverpool. *Fig.* 2 is an elevation of its concave side. *Fig.* 3 a horizontal section through the gate, immediately above the sill. *Fig.* 4, a horizontal section under the top rail.

The framing of each gate or leaf consists of a heel-post, on a pivot fixed to which the gate turns; of a head-post, or, as it is sometimes called, a mitre-post, and thirteen curved horizontal rails, called bars or ribs, tenoned into the head and heel posts. The whole are fastened by iron straps on each side securely bolted. The vertical straps, it will be seen, have horizontal branches at each rib, and the diagonal strap, serving as a tie, is united to it at the top. The ribs are rebated to receive the close planking which extends to the first rib under the top, and which is flush with their face. There are also three vertical posts on each side of the gate, at equal distances apart, securely bolted, extending from the bottom of the gate to the top of the rib where the planking ends. The back of the heel-post is formed truly circular in section to fit closely the segmental groove in the stone work, called the hollow quoin. Each gate is hung at the top with a wrought-iron collar in a cast-iron anchor block let into the stone-work, and at the bottom it turns on a pivot pin of hard brass, moving in a cast-iron cup let into the masonry (see the detailed drawing of this, *Fig.* 7, Plate LXII.) The top of the pivot is let into a brass socket fixed in the bottom of the heel-post by wedging, and between them there is interposed a ball of hard steel. All these parts are truly turned and fitted. The outer end of each gate is supported by a brass roller with a lever adjusting apparatus. The roller traverses the cast-iron segments let into the masonry, as seen in *Fig.* 3, and detailed in section in *Fig.* 6, Plate LXII.

The two central divisions, formed by the vertical bars, contain the paddles or sluices, which are formed of cast-iron faced with brass, and work in cast-iron framing let into the gate.

Part of the cast-iron work of the sluices is shown in detail in *Fig.* 5, Plate LXII., and the whole of their moving parts will be understood by an inspection of *Fig.* 1 of the same plate.

On the top of the gate is a gangway, supported on brackets, and provided with iron stanchions, and chains

or rails as a fence. The outside stanchions are fitted in sockets, and are made to unship.

PLATE LXII.—*Fig.* 1 is the elevation, *Fig.* 2 a vertical section, and *Figs.* 3 and 4 horizontal sections of the top and bottom of one of the gates of the Victoria Dock, Hull; and *Figs.* 5, 6, and 7 are details of the parts which have been already referred to. The description of the construction of the Coburg Dock gates applies equally to this, and need not be repeated. The following is an extract from a specification of the engineer of these works, Mr. J. B. Hartley, for a gate of similar dimensions:—

There are to be two pairs of gates for a clear opening of 60 feet from the outer face of the hollow quoins. The ribs, heads, and heels of these gates are to be either of English oak of the very best and quickest grown timber; or of African oak, but no mixture of these woods in the framing of any gate will be allowed. The planking to be of greenheart timber. Each rib, head, and heel of each gate is to be formed of a single and self-contained piece of timber squared through to the full dimensions figured upon the drawings. The whole of the bolts, spikes, nuts, washers, and all other wrought-iron work connected with the gates, excepting the up and down cross and diagonal straps, the gangway-stanchions, and anchor-bolts, are to be galvanized in the best possible manner.

The sluices in the gates are to be faced with brass, and fitted up in every respect in the best style of workmanship, and in every respect in accordance with the drawings.

A cast-iron cup must be prepared and let into the masonry to receive the pivot pin in the heel of each gate.

These pivot pins are to be of hard brass, and to be truly turned, so as to fit the cup, and also a steel ball working between the top of the pin and the heel casting as shown, &c., which must be bored to receive them, as also must the heel castings of the gates. The heel castings are to be of hard brass, firmly wedged into the foot of the heel-post.

When the gates have been framed and fitted together the heels are to be dressed off truly round, and are to be completely covered for 15 feet above the heel castings, with broad, flat-headed copper nails, 226 to the pound, to fit the hollow quoins, which must be rubbed and polished perfectly smooth, and truly vertical from top to bottom, in the hollow between the water lines, to receive them.

The segment plates, on which the truck wheels of the gate are to travel, are to be of cast iron, in every respect in accordance with the drawings; they are to be carefully bedded down, very truly, upon the masonry prepared to receive them, and when bedded are to be fastened down by lewis bolts, as shown upon the drawings.

Crab-boxes and gearing are to be provided on the gangway of each gate to work the sluices in the gates.

Wrought-iron stanchions are to be fixed on the inside of the gangway of each gate of a permanent character, and are to be provided with two rails of $1\frac{1}{2}$ inch round iron, screwed up to each stanchion, on each side, as shown in the drawings.

The stanchions on the outside of the gangways are to be moveable, and made to ship and unship into sockets provided for them; these moveable stanchions are to be provided with chains of galvanized quarter-inch round iron. Anchor-blocks are to be provided of cast iron, and let into the top of each set of hollow quoins, from which the anchor-bolts are to be carried into the masonry provided for the purpose.

These bolts are to be of $2\frac{1}{2}$-inch round iron, and are to be provided at each end with sufficient screws and washers, and are, when let into masonry, to be run round with lead and securely fixed.

PART SIXTH.

JOINERY.

MOULDINGS.

PLATES LXIII.—LXIX.

Before entering on the consideration of the subject of Joinery, it may be well, as introductory to it, to illustrate and describe the various ornamental mouldings which may have to be formed by the joiner.

PLATE LXIII.—Grecian and Roman versions of the same mouldings are shown on this plate.

Fillet or Listel right-angled mouldings require no description.

The Astragal or Bead.—To describe this moulding, divide its height into two equal parts, and from the point of division as a centre, describe a semicircle, which is the contour of the astragal.

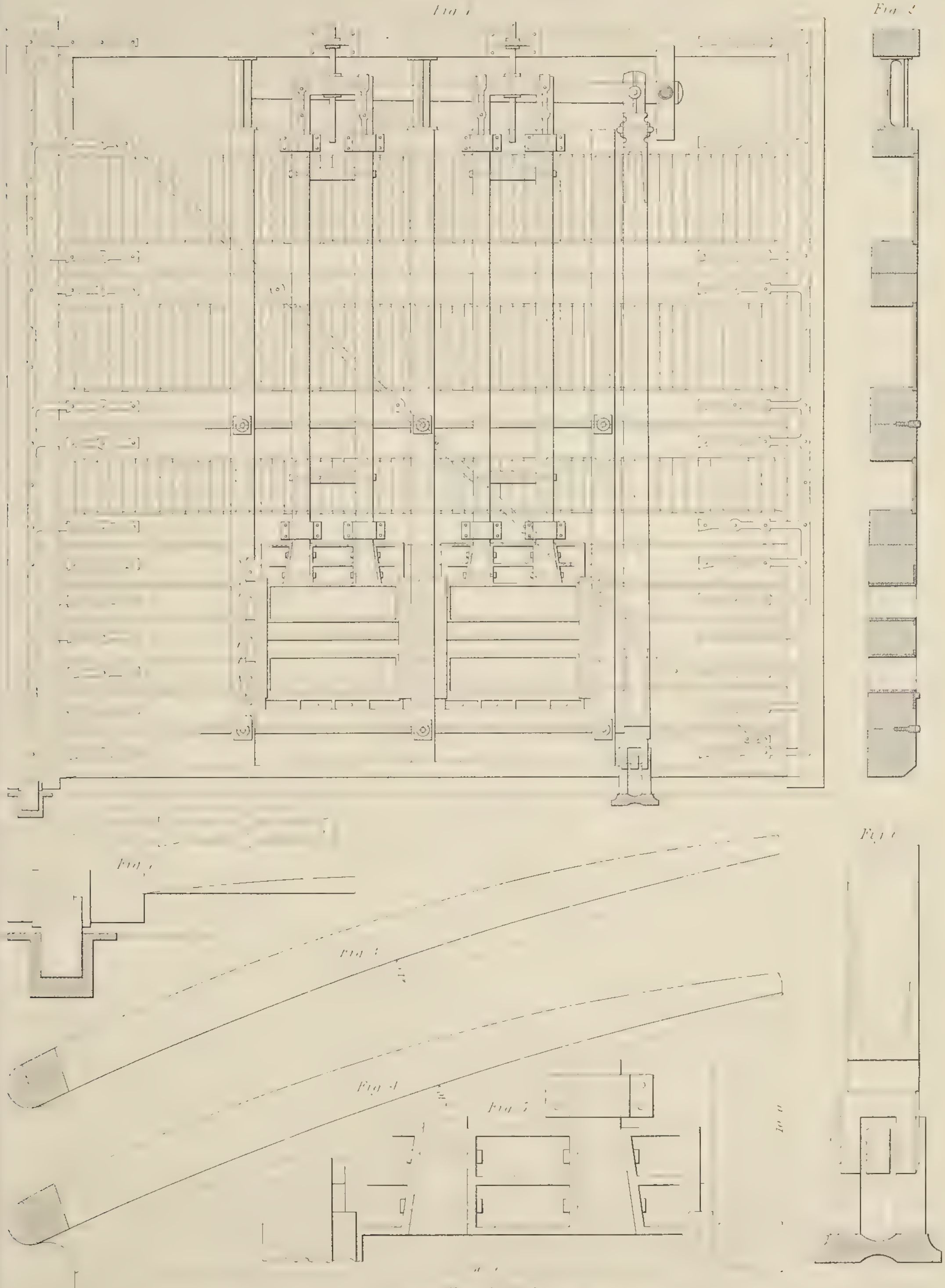
Doric Annulets.—The left-hand figure shows the Roman, and the right-hand figure the Grecian form of this moulding. To describe the latter proceed thus:—Divide the height *b a* into four equal parts, and make the projection equal to three of them. The vertical divisions give the lines of the under side of the annulets, and the height of each annulet, *c c*, is equal to one-fifth of the projection; the upper surface of *c* is at right angles to the line of slope.

Listel and Fascia.—(Roman.)—Divide the whole height into seven equal parts, make the listel equal to two of these, and its projection equal to two. With the third vertical division as a centre, describe a quadrant. (Grecian.)—Divide the height into four equal parts, make the fillet equal to one of them, and its projection equal to three-fourths of its height.

Cavetto or Hollow.—In Roman architecture this moulding is a circular quadrant; in Grecian architecture it is an elliptical quadrant, which may be described by any of the methods given in the first part of the work.

GATES.

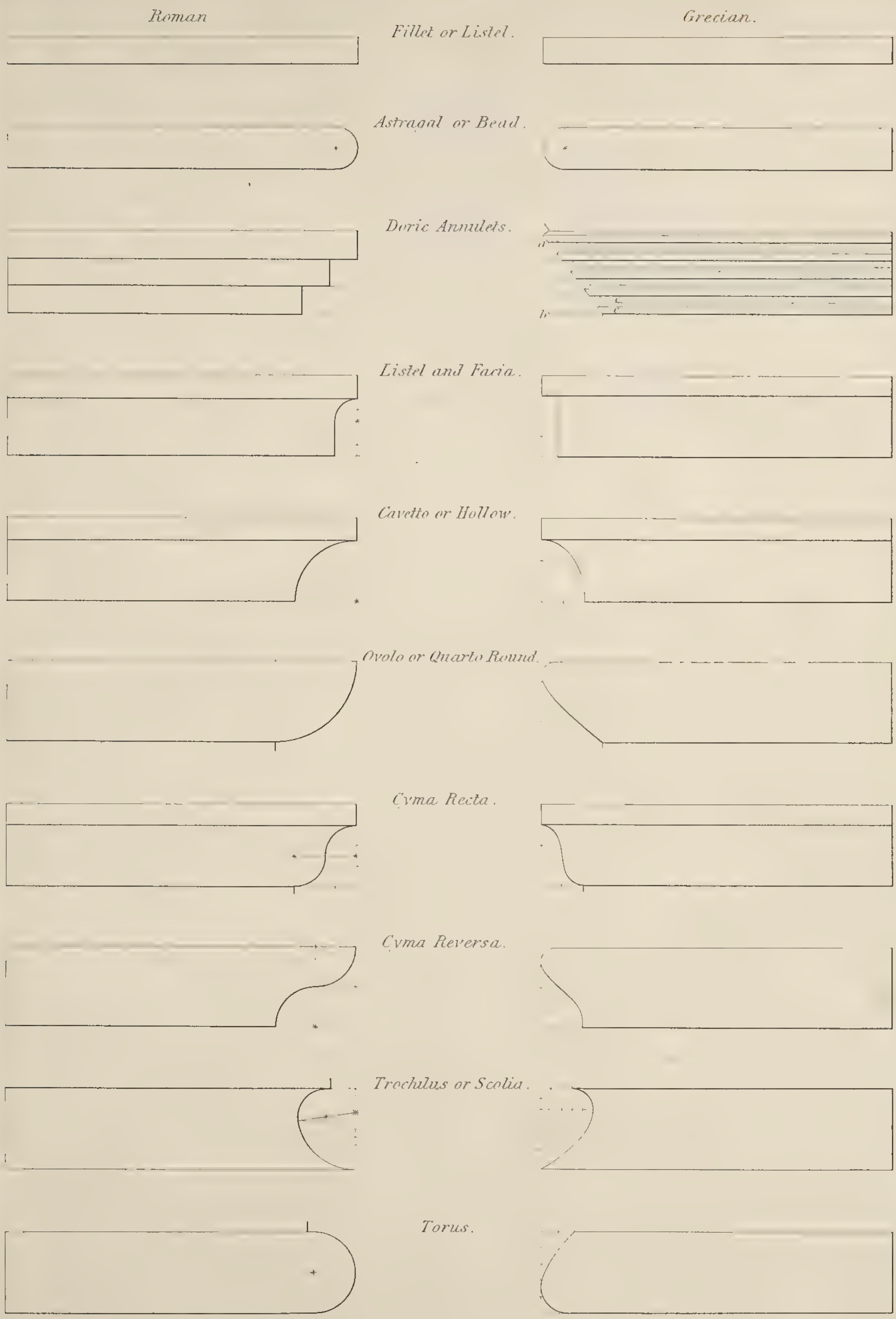
Outer gate of the Victoria Dock, Hull



Scale to Figs. 1, 2, 4

Scale to Figs. 5, 6

MOULDINGS.



J. White. del

BLACKIE & SON, GLASGOW, EDINBURGH & LONDON

W. A. Beever Sc

MOULDINGS

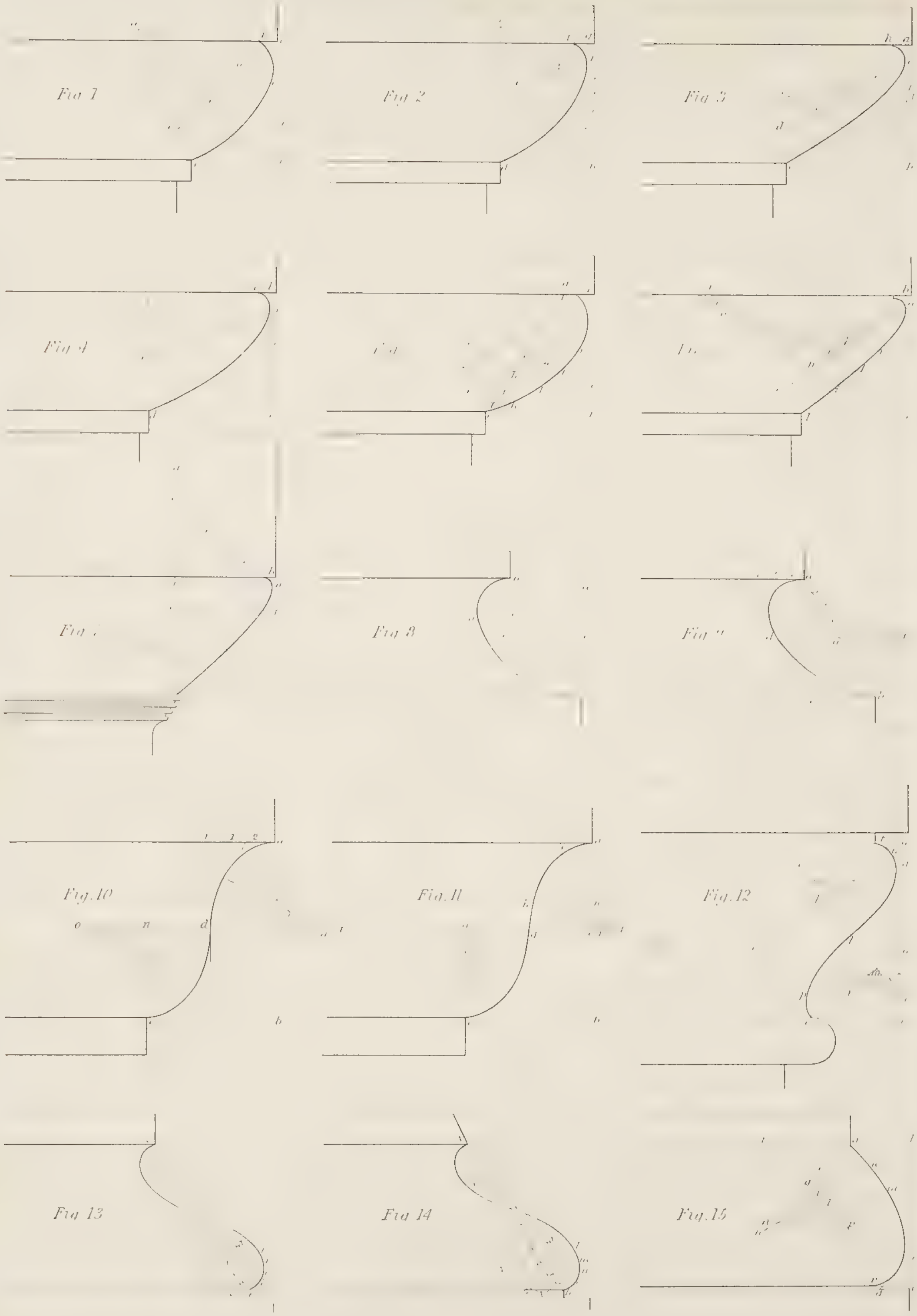


Fig 1
Fig 2
Fig 3
Fig 4
Fig 8
Fig.10
Fig.11
Fig.12
Fig 13
Fig 14
Fig.15

Ovolo or Quarter-round.—This is a convex moulding, the reverse of the cavetto, but described in the same manner.

Cyma Recta.—A curve of double curvature, formed of two equal quadrants. In the Roman moulding these are circular, and in the Grecian moulding elliptical.

Cyma Reversa.—A curve of double curvature, like the former, and formed in the same manner.

Trochilus or Scotia.—A hollow moulding, which, in Roman architecture, is formed of two unequal circular arcs, thus:—Divide the height into ten equal parts, and at the sixth division draw a horizontal line. From the seventh division as a centre, and with seven divisions as radius, describe from the lower part of the moulding an arc, cutting the above horizontal line, and join the centre and the point of intersection by a line which bisects; and from the point of bisection as a centre, with half the length of the line as radius, describe an arc to form the upper part of the curve. There are many other methods of drawing this moulding. The Grecian trochilus is an elliptical or parabolic curve, the proportions of which are shown by the divisions of the dotted lines.

The Torus.—The Roman moulding is semi-cylindrical, and its contour is of course a semicircle. The Grecian moulding is either elliptical or parabolic; and although this and the other Greek mouldings may be drawn, as we have said, by one or other of the methods of drawing ellipses and parabolas, described in the first part of the work, and by other methods about to be illustrated, it is much better to become accustomed to sketch them by the eye, first setting off their projections, as shown in this plate, by the divisions of the dotted lines.

PLATE LXIV.—The figures in this plate illustrate various ways of describing the ovolo, trochilus or scotia, cyma recta, cyma reversa, and torus.

Fig. 1.—*The Quirked Ovolo.*—The projection of the moulding is in this case made equal to five-sevenths of its height, as seen by the divisions, and the radius of the circle $b\ c$ is made equal to two of the divisions, but any other proportions may be taken. Describe the circle $b\ c$, forming the upper part of the contour, and from the point g draw $g\ h$, to form a tangent to the lower part of the curve. Draw $g\ a$ perpendicular to $g\ h$, and make $g\ f$ equal to the radius $d\ c$ of the circle $b\ c$, join $f\ d$ by a straight line, which bisect by a line perpendicular to it, meeting $g\ a$ in a. Join $a\ d$, and produce the line to c. Then from a as a centre, with the radius $a\ c$ or $a\ g$, describe the curve $c\ g$.

Fig. 2.—*To draw an ovolo, the tangent* d e, *and the projection* b, *being given.*

Through the point of extreme projection b, draw the vertical line $g\ h$, and through b draw $b\ c$ parallel to the tangent $d\ e$, and draw $c\ d$ parallel to $g\ h$, and produce it to a, making $c\ a$ equal to $c\ d$. Divide $e\ b$ and $c\ b$ each into the same number of equal parts, and through the points of division in $c b$ draw from a straight lines, and through the points of division in $e\ b$ draw from d right lines, cutting those drawn from a. The intersections will be points in the curve.

Fig. 3.—*To draw an ovolo under the same conditions as before, viz., when the projection* f, *and the tangent* c g, *are given.*

The mode of operation is similar to the last: $f d$ is drawn parallel to the tangent $c\ g$, and $c\ d$ parallel to the perpendicular $a\ b$, $d\ e$ is made equal to $c\ d$, and $d\ f$ and $g\ f$ are each divided into the same number of equal parts.

Fig. 4.—In this the same things are given, and the same mode of operation is followed. By these methods, and those about to be described, a more beautiful contour is obtained than can be described by parts of circular curves.

Fig. 5.—Divide the height $b\ a$ into seven equal parts, and make $a\ r$ equal to $b\ o$ $1\frac{1}{2}$ of a division; join $c\ r$, and produce it to d, and make $c\ d$ equal to $8\frac{1}{2}$ divisions. Bisect $c\ d$ in i, and draw through i, 4 i at right angles to $c\ d$, and produce it to e; make $i\ e$ equal to $b\ o$, and from e as a centre, with radius $e\ c$ or $e\ d$, describe the arc $c\ d$. Then divide the arc into equal parts, and draw ordinates to $c\ d$, in 1 f, 2 g, 3 h, 4 i, &c., and corresponding ordinates $f\ k$, $g\ l$, $h\ m$, $i\ n$, to find the curve.

Fig. 6.—This is an application of Problem LXXXVIII., page 24. The height is divided into eight equal parts, seven of which are given to the projection dc. Join d and the fifth division e, and draw $d\ a$ at right angles to $d\ e$. Make $d\ f$ equal to two divisions, and draw $f\ g$ parallel to $d\ e$, then $d\ f$ is the semi-axis minor, and $d\ g$ the semi-axis major of the ellipse; and the curve can either be trammelled or drawn by means of the lines $a\ h$, $m\ k$, $o\ p$, being made equal to the difference between the semi-axis, as in the problem referred to.

Fig. 7.—*To describe the hyperbolic ovolo of the Grecian Doric capital, the tangent* a c, *and projection* b, *being given.*

Draw $d\ e\ g\ k\ a$ perpendicular to the horizon, and draw $g\ h$ and $e\ f$ at right angles to $d\ e\ g\ k\ a$. Make $g\ a$ equal to $d\ g$, and $e\ k$ equal to $d\ e$; join $h\ k$. Divide $h\ k$ and $f\ h$ into the same number of parts, and draw lines from a through the divisions of $k\ h$, and lines from d through the divisions of $f\ h$, and their intersections are points in the curve.

Fig. 8 is an elegant mode of drawing the Roman trochilus. Bisect the height $h\ b$ in e, and draw $e\ f$, cutting $g\ c$ in f; divide the projection $h\ g$ into three equal parts, make $e\ o$ equal to one of the divisions, and $f\ d$ equal to two of them, join $d\ o$, and produce the line to a. Make $d\ c$ equal to $d\ g$, and draw $c\ b$, and produce it to a. Then from d as a centre, with radius $d\ a$ or $d\ g$, describe the arc $g\ a$; and from o as a centre, with radius $o\ a$, describe the arc $a\ b$.

Fig. 9 shows the method of drawing the Grecian trochilus by intersecting lines in the same manner as the rampant ellipse, Fig. 167, page 24, with which the student is already familiar.

Fig. 10 shows the cyma recta formed by two equal opposite curves, imitations of the ellipse, drawn in the manner taught in Problems XV. and XVI., Figs. 174 and 175, page 26. By taking a greater number of points as centres, a figure resembling still closer the true elliptical curve will be produced.

Fig. 11 shows the cyma recta formed with true elliptical quadrants, described as taught in Problem LXXXVIII., or they may be trammelled by a slip of paper, as in Fig. 163, page 24.

Fig. 12 shows the cyma reversa, obtained in the same manner. The lines $c\ d$, $e\ h$ are the semi-axes major, and the line $o\ n$ is the semi-axis minor, common to both curves. As in the former case, these lines, and the heights

k l, *m l*, being obtained, the curve can be trammelled with a slip of paper.

Figs. 13 and 14 show the cyma recta used as a base moulding, and obtained by means of ordinates from circular arcs. The student is familiar with this process, and therefore no description is required.

Fig. 15.—The Grecian torus is here drawn as in Problem LXXXVIII.; *f c* is the line of the major, and *a h* the line of the minor axis of the ellipse.

It is obvious that the relation of the projection to the height, in all these mouldings, may be infinitely varied; but if the student has paid attention to the construction of the ellipse, parabola, and hyperbola, elucidated in pages 22 to 28, and to the application of the methods there described, and the illustrations now offered, these variations will not embarrass him. But it is necessary to repeat that it is better, after the eye has become familiarized with the graceful forms of the Grecian mouldings, to trust to the curves produced by sketching, as then the proportions may be varied to infinity, as in the ancient examples.

PLATE LXV. contains a series of illustrations, designed by Mr. White, of the application of the Grecian mouldings, just described, in joiner-work. With the exception of the beads, the curves all belong to those derived from the sections of a cone. They are intended to show the infinite variety that may be produced by the combination of simple elements.

The mouldings just described are generally denominated *classic*, because they are derived from examples left us by the Greeks and Romans. But the architecture of the middle ages affords examples of moulded work which are no less attractive in their forms, and which possess qualities which render them especially serviceable for the use of the joiner. To the illustration of these we have devoted a single plate, described below, and it is only to the elementary forms that the limits of this work admit of pointing the attention. But the forms and combinations are so peculiarly suggestive, that with ordinary fancy and intelligence the combinations may be infinitely varied. To exhaust the subject would require a volume.

Classic architecture is usually divided into orders. Thus, there are the Tuscan, the Doric, the Ionic, the Corinthian, and the Composite orders. The mouldings used in these are nearly alike in form, and their combination chiefly marks the order to which they belong. In Gothic architecture there are no orders, but there are distinctive evidence of progress, of perfection, of decadence. Hence in place of orders we have periods, which are called styles, and these have been settled by almost general consent. First, there is the Norman period or style, then the period of the early English, to this succeeds the Decorated style, and it is again succeeded by the Perpendicular style.

In regard to the mouldings, those belonging to the first period or style are distinguished by their simplicity and strength of character. The next period shows more elaboration, without much diminution of strength. The third, or Decorated period, adds variety and intricacy; and to this, in the fourth and last style, succeeds a poverty and meagreness sufficiently marked, and indicative of decay, in so far as great works are concerned, yet not inapplicable, as we shall see, to the ordinary every-day wants of life.

The first or Norman period is characterized generally by square sinkings, with the angles sometimes truncated and sometimes moulded; the second or early English period, by deep undercut hollows, between prominent members, and pointed or filleted boutels; the third or Decorated period, by roll and fillet mouldings, nearly resembling the early English, and a succession of double ogees, divided by hollows formed of three quarters of a circle; the fourth or Perpendicular period, by larger and coarser mouldings, wide and shallow hollows, hard edges, in place of rounded forms, and all generally arranged on the chamfer plane.

PLATE LXV.[a]—*Gothic Mouldings.*—*Fig.* 1 is a jamb belonging to the first period, called the Norman; *a b* and *d c* are called chamfer planes. In *Fig.* 2, of the same period, more variety is obtained by making square sinkings, and truncating the angles by a smaller chamfer plane, as at *a b*.

Fig. 3, of the second period, shows square sinkings with the angles truncated by a shallow cavetto. *Fig.* 4 shows a square sinking, the angles truncated by a cavetto, and a pointed boutel at *b*, and a round boutel at *a*.

Figs. 5, 6, and 7 belong to the Decorated period. Here the mouldings assume a greater variety and contrast of form. The faces of the square sinking in *Fig.* 5 are joined by a three-quarter circle in the angle at *b*, and the roll and fillet moulding at *a* is undercut and separated from the chamfer plane by two three-quarter circles, and the double ogee at *c* is formed on the chamfer plane.

In *Fig.* 6 the double ogee again occurs on the chamfer plane.

Fig. 7 shows the mouldings of a window in this style.

Figs. 8 and 9 belong to the Perpendicular period.

Fig. 10 is the section and elevation of an early English capital and base; *Fig.* 11, of a Decorated capital and base; and *Fig.* 12, of a Perpendicular capital and base.

Figs. 13 to 26 are sections of string-courses and cornices, of which *Figs.* 13 to 16 are early English, *Figs.* 17 to 20 are of the Decorated period, and *Figs.* 21 to 26 belong to the Perpendicular.

Fig. 27, also, is a cornice belonging to the Perpendicular period, wherein a beautiful effect is produced by the pieces *a a*.

Fig. 28, No. 1 is the section, and No. 2 the elevation of a Perpendicular cornice.

Fig. 29, No. 1 is the side, and No. 2 the front elevation of a bench-end. In No. 1 the sections *c d a b* show how the edge proceeds from the square at *k* to the chamfer plane, and from the chamfer plane to the moulding, returning to the square by the quarter circle at *e f*.

Fig. 30, Nos. 1 and 2 show a variety in the chamfering at *c d* and *a b*.

Fig. 31 shows mouldings on the chamfer plane, and the return to the square arris.

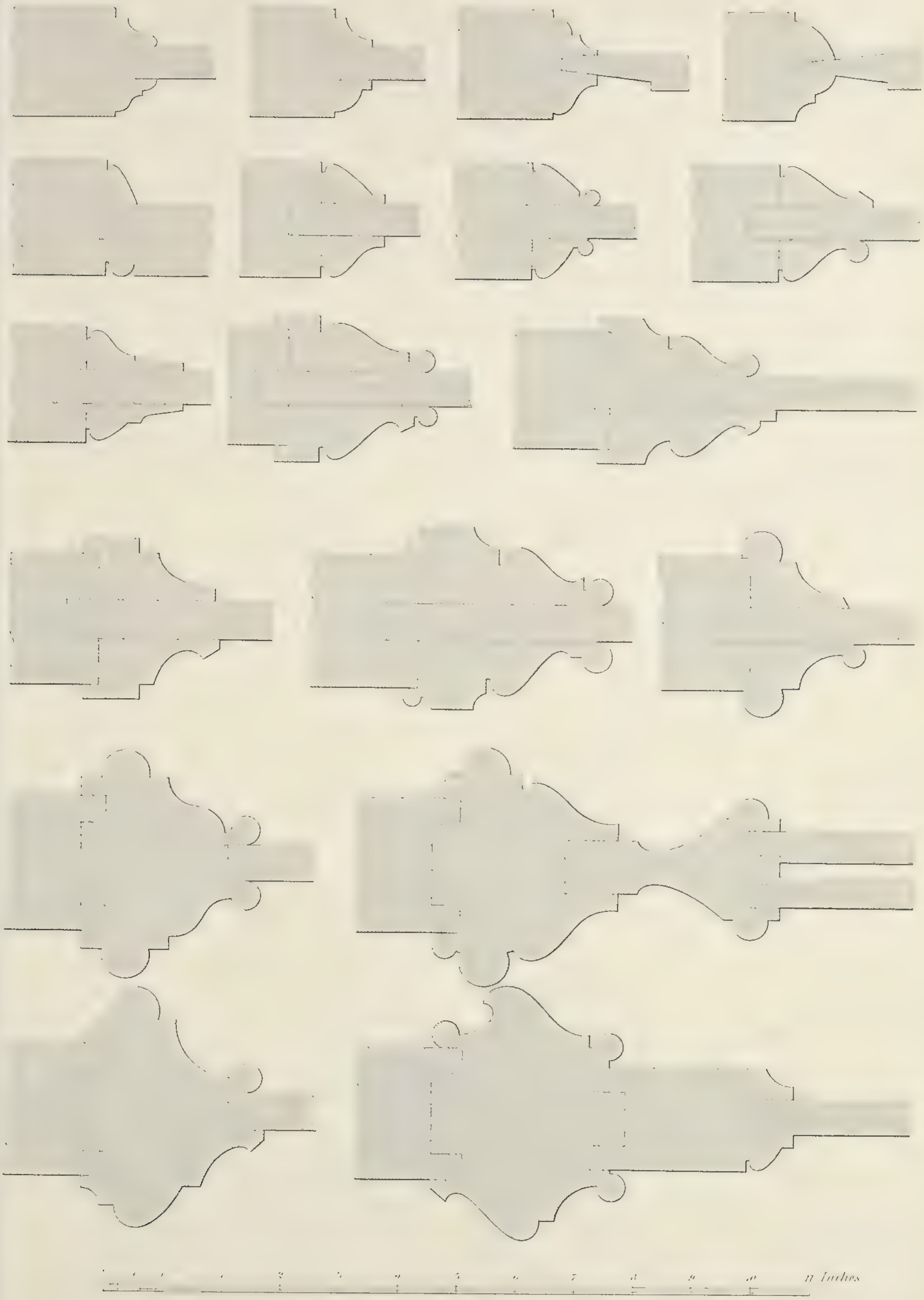
Fig. 32, Nos. 1 and 2 the front and side of a moulded bracket.

Fig. 33 is the elevation of part of a door frame; *a b c d* is a section showing the form and projections of the mouldings.

Fig. 34 is the manner of ornamenting a small panel; *a b* is a section through the mouldings.

Fig. 35 is a larger panel similarly ornamented.

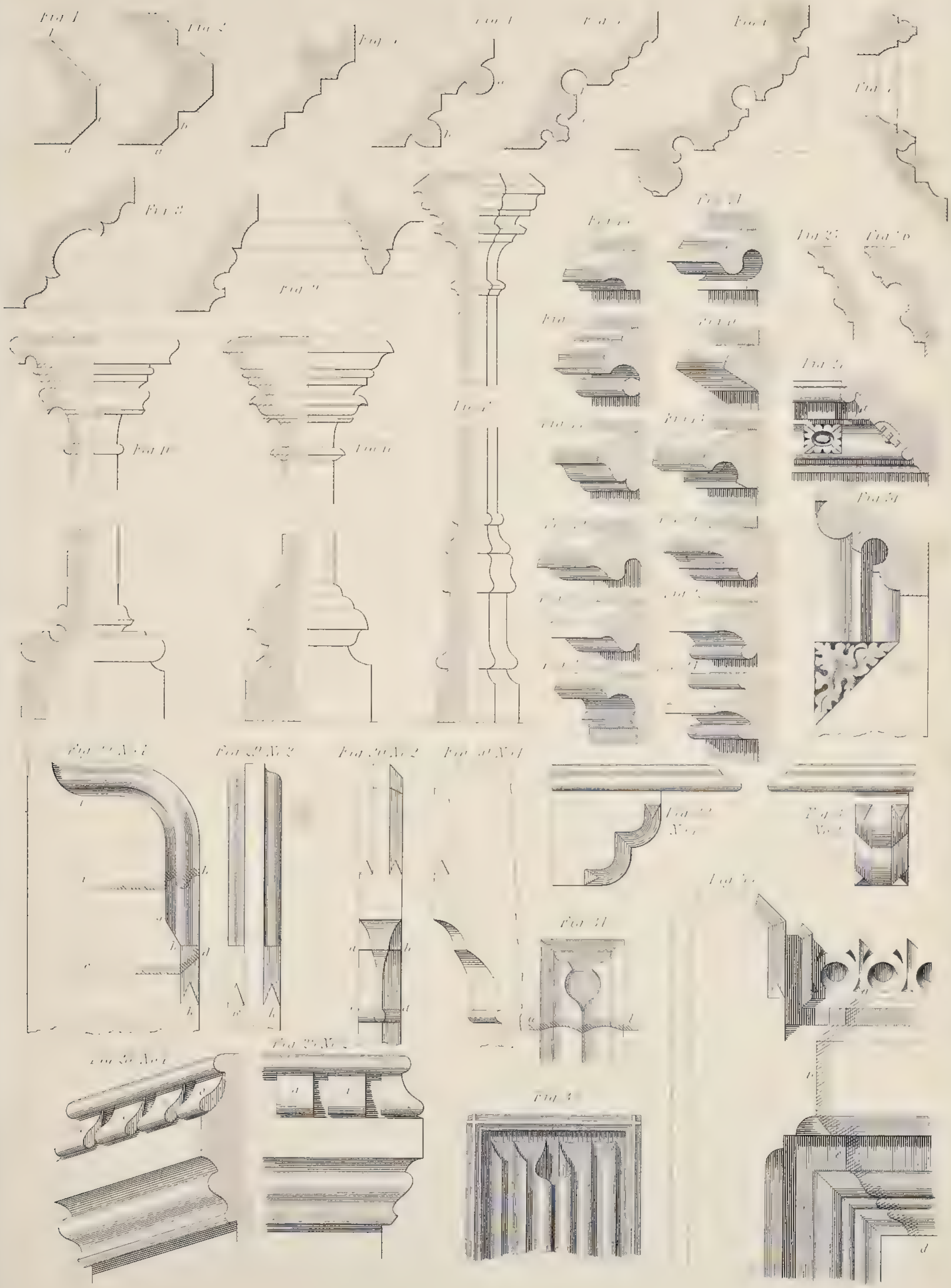
MOULDINGS.



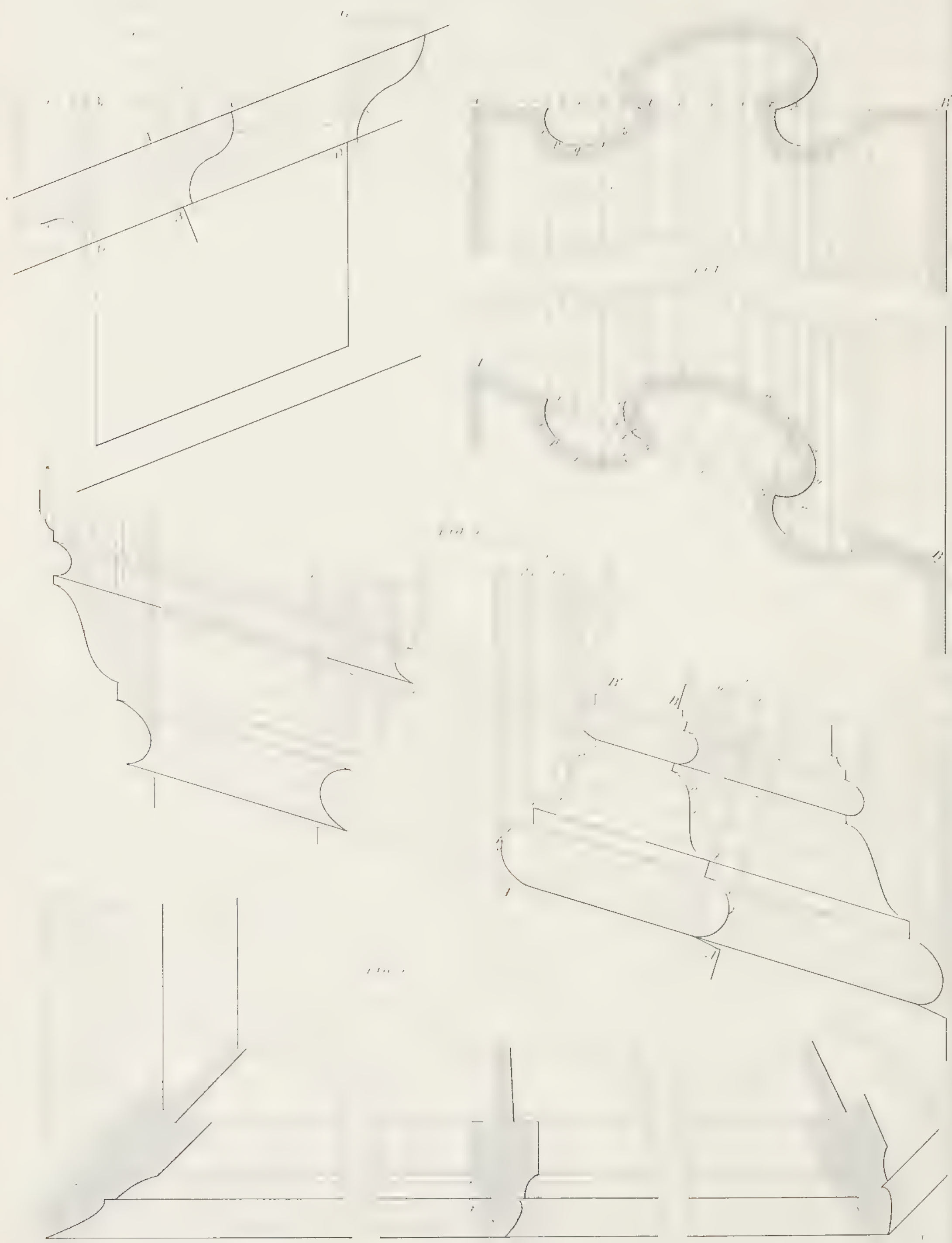
W. C. Moss del. W. A. Beever Sc.

GOTHIC MOULDINGS

PLATE LX.

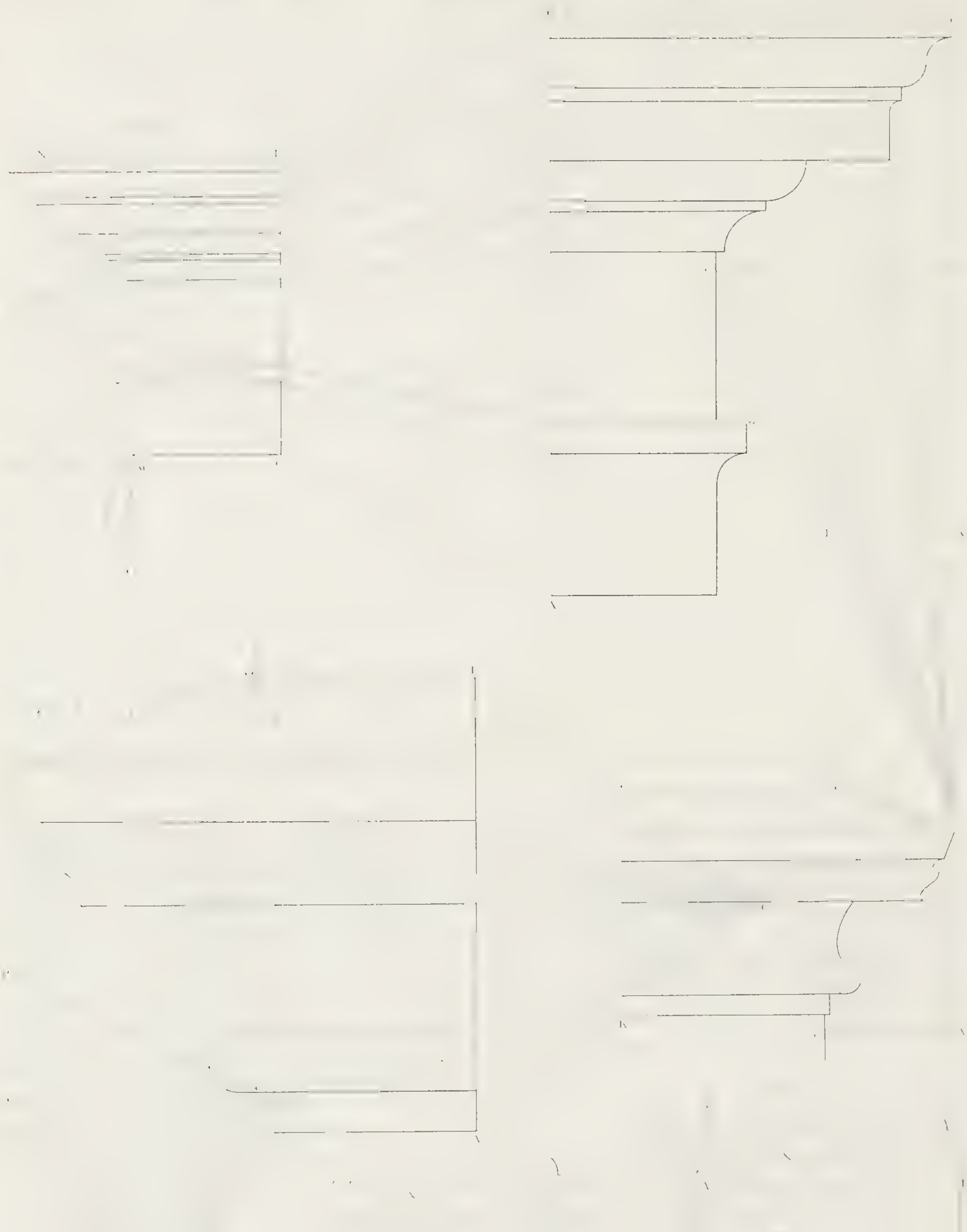


RAKING MOULDINGS.



W. C. Jones, del.

BLACKIE & SON, GLASGOW, EDINBURGH & LONDON



RAKING MOULDINGS.

Plate LXVI.—*Fig.* 1 shows part of the raking cornice of a pediment, with the horizontal part of the moulding on the left of the figure. Draw *g o* perpendicular to the horizon, and *o h* at right angles to *g o*. In *o h* take any point, *l*, and draw *l d* parallel to *g o*, and cutting the profile in *d*, and through *d* draw a line *d x*, parallel to the line of rake. Then to find the section of the raking front, draw any line, A B, perpendicular to *d x*, and make A *r* equal to *o l*, and draw *r x* parallel to A B, cutting *d x* in *x*; then the point *x* is a point in the raking profile. In the same manner any other point, such as *z y w v* corresponding to *f e c b*; may be found.

When the moulding is returned at the upper part, such as at H F, the line H G must obviously be drawn parallel to *g o*, that is, perpendicular to the horizon. The remainder of the procedure, and the manner of finding the return of the bed moulding R S at H P, is too obvious to require further description.

Fig. 2 shows a raking moulding on the spring. In this the procedure is the same as in the last, except that in place of drawing lines parallel to the rake, concentric curves are described to find the points in the moulding. But it is necessary to observe that it is not where the perpendiculars from A C intersect these arcs that the proper points are. The true points are intersections with tangents to the curves where they cut the line A B.

Figs. 3 and 4 show the method of describing the section of the raking moulding on the line A B perpendicular to the raking line, and also on the line G H parallel to *g o*, in the case where the moulding is not returned, or where the two raking sides meet. These will be readily understood on inspection.

Plate LXVII.—*Fig.* 1 shows the manner of drawing a modillion in a raking cornice. The mode of operating is precisely as in *Fig.* 1 of Plate LXVI., and need not be repeated.

Fig. 2 is a raking architrave, and *Fig.* 3 a base moulding, both of which are sufficiently intelligible without lengthened description.

Fig. 4 shows the method of describing the angle-bars of a window: No. 1 being the ordinary bar; No. 2, a mitre bar; and No. 3, a bar occupying an obtuse angle. The line *a m* is in all three cases drawn perpendicular to the axis of the bar; and the divisions, *a b c d*, &c., of No. 1, are transferred to Nos. 2 and 3, and lines perpendicular to *a m* drawn to meet the lines *a b c d*, which pass through points of the moulding.

ENLARGING AND DIMINISHING MOULDINGS.

Plate LXVIII., *Fig.* 1.—Let A B be the height of a cornice which it is proposed to diminish. On A B construct an isosceles triangle A E B, and parallel to A B draw G H, equal to the proposed height. Then from E draw lines from the horizontal divisions of the cornice on A B, and the points in which these cut the line G H give the new heights. To find the projections: draw, at the right side of the figure, any horizontal line, C D, and on it draw perpendiculars from the projections of the various members of the cornice; produce the extreme perpendiculars indefinitely: make D F equal to the perpendicular height of the isosceles triangle A E B, and from the divisions on C D draw lines to the point F. On F D set off F K, equal to the perpendicular height of the isosceles triangle G E H, and draw I K parallel to C D. The divisions on I K, transferred to L M, on the left of the figure, give the projections diminished in the same ratio as the heights.

Let it now be required to enlarge the cornice at the left side of this figure. From the point G, with the proposed height of the cornice in the compasses, cut the line H N in N, and join G N: the points where this line is intersected by the horizontal lines of the mouldings are the heights of the members, enlarged in the same ratio as the whole height. To find the projections, from the point L draw the line L O, making the angle M L O equal to the angle H G N, and it will be cut by the lines of projections produced in the same ratio as G N is by the horizontal lines.

In place of drawing L O, as described, the same result would be obtained by drawing a line at right angles to G N, crossing the lines of projection.

Fig. 2 is a further exemplification of the manner of enlarging and diminishing mouldings. First, as to enlarging:—From the point A, with the proposed increased height in the compasses, cut B O in O, and join O A, and this line will be divided by horizontal lines, drawn from any point, as *a b*, in the mouldings, in the proportion that O A bears to B A. Then, to find the projections, draw E P, making the angle D E P equal to the angle B A O, and vertical lines drawn from the same points in the mouldings as the horizontal lines will give the corresponding increased projections on P E.

Next, as to diminishing:—On A B construct an isosceles triangle A C B, and draw to C radial lines from the points of intersection of the horizontal divisions with A B. Draw I K parallel to A B, and equal to the proposed diminished height; then, to find the diminished projections corresponding to the divisions on I K: construct on D E an isosceles triangle D F E, having its vertical height equal to the vertical height of the triangle A C B on A B. To F draw radial lines from the divisions produced by perpendiculars drawn on D E from the points of projection, and intersect these by G H drawn parallel to D E, and at the same distance from it as I K is from A B. The divisions on G H, transferred to L M, at the right side of the figure, are the diminished projections.

Fig. 3 shows the manner of finding the proportions of a small moulding which is required to mitre with a larger one, or *vice versa*. Let A B be the length of the larger moulding, and A D the length of the smaller one; construct with these dimensions the parallelogram A D C B and draw its diagonal A C; draw parallel to B C lines *a s*, *b t*, &c., &c., meeting the diagonal in *s t*, &c., and from these points draw parallels to A B, meeting A D in *n o p r*; produce them to *i k l m*, &c., and make *n i* equal to *e a*, *o k* to *f b*, &c., and thus complete the contour of the moulding on D A, the lengths of which are diminished in the ratio of A D to A B, but its projections remain the same as those of the larger moulding. The operation may be reversed, and the larger produced from the smaller moulding.

Fig. 4 shows the manner of enlarging or diminishing a single moulding. Let A B be a moulding which it is required to reduce to A D. Make the sides A B, D C, and A D, B C of the parallelograms respectively equal to the

larger and smaller moulding, and draw the diagonal A C, produce D A to E, and make E A F equal to a, A, b, and draw A F. The manner of obtaining the lengths and projections with these data is so obvious that further description is unnecessary.

PLATE LXIX.—All the figures in this plate are illustrations of architraves, with the exception of No. 12, which is a triple corner bead. In the figures of architraves the shaded parts are the horizontal section across the mouldings, and the single line beyond the shaded part is the outline of the block or plinth on which the architrave stands.

JOINERY.

Joinery is the art of cutting out, dressing, uniting and framing wood for the external and internal finishings of buildings. It has been broadly distinguished from carpentry by this, that while the work of the carpenter cannot be removed without affecting the stability of a structure, the work of the joiner may. The labours of the carpenter give strength to a building, those of the joiner render it fit for habitation.

In joinery the parts are nicely adjusted, and the surfaces exhibited to the eye are carefully smoothed.

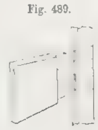
The goodness of the work of the joiner depends first on the perfect seasoning of the materials, and, second, on the care of the operator. All the surfaces must be perfectly out of winding and smooth. The stuff must be square, the mouldings true and regular, and all must be so fixed as to bring out the beauty of the wood. The moving parts must work with ease and freedom.

Many of the operations described in carpentry and joinery appear to be common to both, and such as may be performed indifferently by the carpenter or the joiner; but in reality it is not so, for a man may be a competent carpenter without being a joiner at all, and although a joiner may be able to execute carpentry work, yet the habits of greater neatness and precision required in the practice of his own proper art, make his services less profitable in carpentry work.

The timber on which the joiner operates is termed *stuff*, and consists of boards, planks and battens. A board is a piece of timber from 7 to 9 inches wide. A plank is a piece whose width is great in proportion to its thickness, but the term is generally applied to pieces above 9 inches wide and not more than 4 inches thick. A batten is a piece from 2 to 7 inches wide. These terms are used in a more restricted sense than this in some places, as for example in London, where a batten means a fine flooring-board, 7 inches broad and $1\frac{1}{2}$ inch thick, but the definition applies generally.

On stuff like this described the joiner operates by sawing, planing, mortising, grooving, dovetailing, and moulding; and he fastens the parts of his work together by gluing, wedging, pinning, and nailing.

Fig. 489.

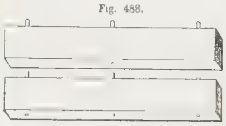


Mortising in joinery is similar to the same operation in carpentry, with the exception of the variation arising from the smallness and neatness of the work. The parts should fit easily together without hard driving, and the tenon should fill the mortise fully and equally. The tenon is generally about one-fourth of the thickness of the framing, and its width about five times its thickness. If, therefore, the piece of wood to be tenoned be very wide a double tenon should be formed, as in Fig. 489.

If the piece of wood be also thick as well as wide, two projections, resembling short tenons, and called *stump-tenons*, are made, one on each side of the main tenons, and these fit into corresponding grooves in the mortised piece; and the tenons at the end of framing should be set back a little, to allow of sufficient strength of wood for the mortising. This is called *haunching*.

As the stuff on which the joiner operates is of limited width, and it is frequently necessary to cover large surfaces, recourse is had to various modes of joining the pieces laterally. In these *joints*, as they are termed, several expedients, as circumstances require, are used for the purpose of preventing air or dust blowing through; and also preventing the inevitable shrinkage of the timber detracting from the appearance of the work. These lateral joints may be doweled, grooved and tongued, or rebated.

Fig. 488.



Doweling consists in forming corresponding holes in the contiguous edges of the boards, into which cylindrical wooden or iron pins are inserted, as in Fig. 488.

Grooving and tonguing, or *grooving and feathering*, consists in forming a groove or channel along the edge of one board, and a projection or tongue to fit it on the edge of the other board. When a series of boards has to be joined, each board has a groove on its one edge, and a feather or tongue on the other. When the boards are thick, grooves are made on the contiguous edges of both boards, and a small fillet, generally of hard wood, is inserted into both. This is called a *slip-feather* or *tongue*.

Rebating is another method of joining boards by cutting down the contiguous edges of two boards to half their thickness, but on opposite sides, and thus when they are laid together their surfaces are in the same plane.

JOINTS.

PLATES LXX., LXXI.

PLATE LXX.—*Fig.* 1 shows a joint formed by planing the edges of the board perfectly true, and inserting wooden or iron pins at intervals into the edges of both boards. The pin is shown by a dotted line in the drawing. It is called a dowel, and the joint is said to be doweled.

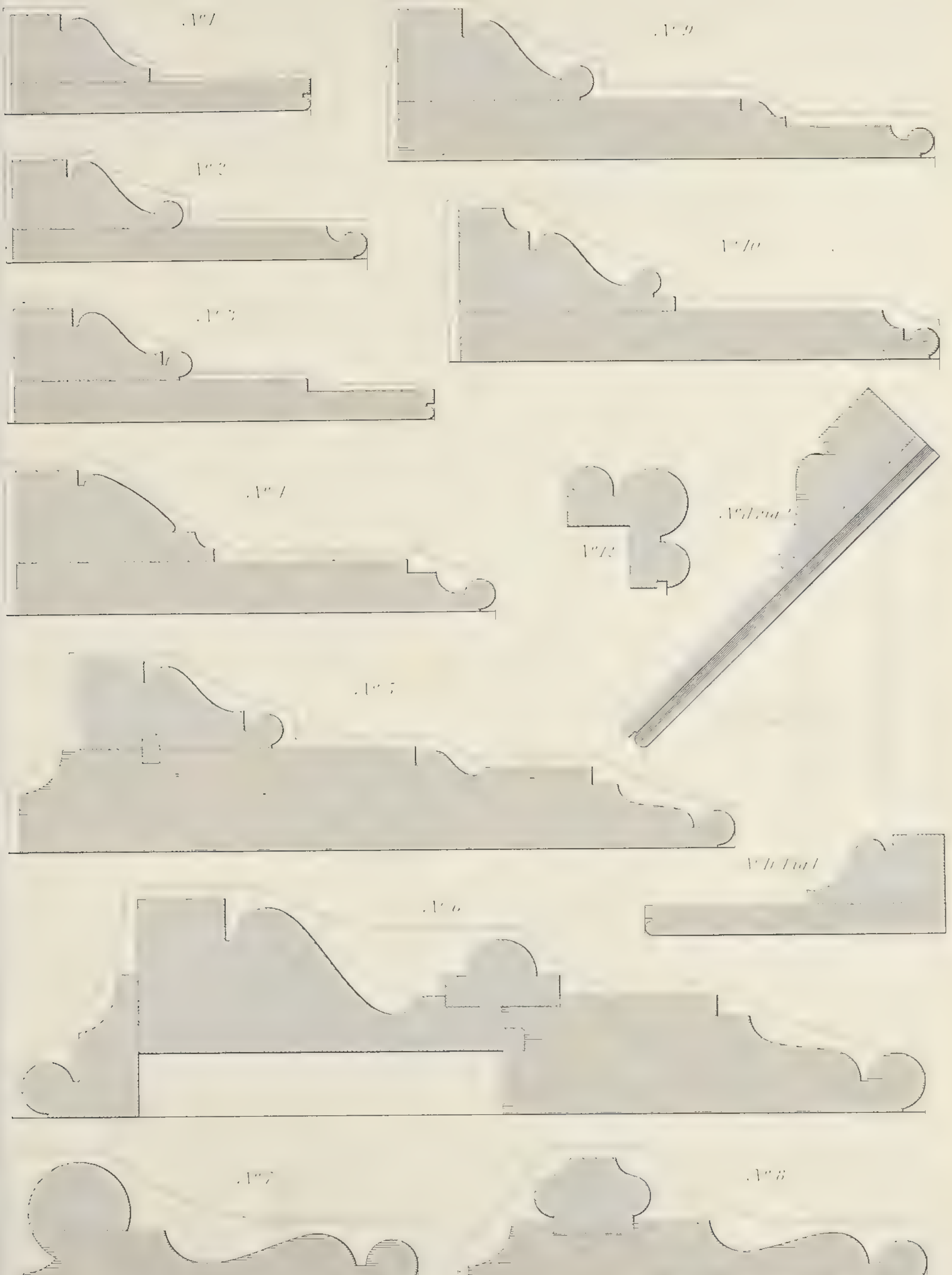
Fig. 2 shows a joint formed by grooving and tonguing, or, as it is variously called, grooving and feathering, ploughing and tonguing, or feathering.

These two last joints are commonly used for floors. The first is used without the dowels in common folded floors. The shrinking of the boards in this case causes the joint to open, and the air and dust pass through. The grooved and tongued joint is used in the better kind of floors. The tongue or feather prevents the passage of air or dust.

Fig. 3 is a double-tongued or feathered joint.

Fig. 4 is a combination of a rebate with a groove and tongue. It affords in flooring a better means of nailing, as the drawing shows.

ARCHITRAVES AND BLOCKS.



W. C. Jeans, del.

JOINTS IN JOINERY

JOINTS FOR PANELS INTERIOR AND EXTERIOR ANGLES &c.

In *Fig.* 5 the groove and tongue are angular.

Fig. 6 is a kind of grooving and tonguing resorted to when the timber is thick, or when the tongue requires to be stronger than it would be if formed in the substance of the wood itself. In this mode of jointing corresponding grooves are formed in the edges of the boards, and the tongue or feather is formed of a slip of a harder or stronger wood. It is called a *slip feather.*

Fig. 7, 8, 9 are examples of slip-feather joints; the feather in *Fig.* 9 is of wrought iron.

Fig. 10 shows dovetail grooves, with a slip feather of corresponding form, which, of course, must be inserted endways.

Fig. 11 is a simple rebated joint. One-half of the thickness of each board is cut away to the same extent, and when the edges are lapped the surfaces lie in the same plane.

Fig. 12 shows a complex mode of grooving and tonguing. The joint is in this case put together by sliding the one edge with its grooves and tongues endways into the corresponding projections and recesses of the other. The boards when thus jointed together cannot be drawn asunder laterally or at right angles to their surface, without rending; but, in the event of shrinking, there is great risk of the wood being rent.

Where a great surface has to be covered with boarding not framed, the deals are cut into narrow widths, and joined at their edges by some of the joints just described. Fig. 490 shows the simple groove-and-tongue joint, which it is evident the shrinkage of the wood will cause to open and disfigure the work. To prevent this disfigurement a small moulding, termed a *bead*, is sometimes run on the edge of each board, as in Fig. 491.

Fig. 490.

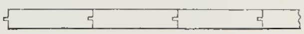
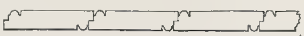


Fig. 491.

Fig. 492.



The joint thus forms one of the quirks of the bead, and prevents any slight opening from the shrinkage of the wood being observed. This is termed a grooved, tongued, and beaded joint. So also in the case of the rebated joint, a bead is run on the edges of the board, and the result is as in Fig. 492. This is termed a rebated and beaded joint.

In joining angles formed by the meeting of two boards various joints are used, among which are those which follow.

Fig. 13.—The common mitre-joint, used in joining two boards at right angles to each other. Each edge is planed to an angle of 45°.

Fig. 14 shows a mitre-joint keyed by a slip-feather.

Fig. 15 shows a mitre-joint when the boards are of different thickness. The mitre on the thicker piece is only formed to the same extent as that on the edge of the thinner piece; hence there is a combination of the mitre and simple butt joint.

Fig. 16 shows a different mode of joining two boards of either the same or of different thicknesses. One of the boards is rebated, and only a small portion at the angle of each board is mitred. This joint may be nailed both ways.

In *Fig.* 17 both boards are rebated, and a slip-feather is inserted as a key. This also may be nailed through from both faces.

Figs. 18 and 19 are combinations of grooving and tonguing with the last-described modes. These can be fitted with great accuracy and joined with certainty.

Fig. 20 is a joint formed by the combination of mitring with double grooving and tonguing, shown in *Fig.* 12. The boards must in this case be slipped together endways, and cannot be separated by a force applied at right angles to the planes of their surfaces.

In all these mitre-joints the faces of the boards meet at the angle, and the slight opening which might be caused by shrinkage would be scarcely observable. In the butt-joints which follow, the face of the one board abuts against the face of the other, the edge of which is consequently in the plane of the surface of the first board, the shrinkage of which would cause an opening at the joint. To make this opening less apparent is the object of forming the bead-moulding seen in the next five figures.

In *Fig.* 21 the thicker board is rebated from the face, and a small bead is formed on the external angle of the abutting board.

In *Fig.* 22 a groove is formed in the inner face of the one board and a tongue on the edge of the other.

In *Fig.* 23 the boards are grooved and tongued as in the last figure. A cavetto is run on the external angle of the abutting board, and the bead and a cavetto on the internal angle of the other board.

In *Fig.* 24 a quirked bead run on the edge of one board, and the edge of the abutting board forms the double quirk.

In *Fig.* 25 a double quirk bead is formed at the external angle, and the boards are grooved and tongued. The external bead is attended with this advantage, that it is not so liable to injury as the sharp arris.

In *Figs.* 26 and 27 the joints used in putting together cisterns are shown

Figs. 28 and 29 are joints for the same purpose. They are of the dovetail form, and require to be slipped together endways.

Figs. 30 to 35 show the same kind of joints as have been described, applied to the framing together of boards meeting in an obtuse angle.

Figs. 36 and 37 show methods of joining boards together laterally by keys, in the manner of scarfing; and *Fig.* 38 shows another method of securing two pieces, such as those of a circular window frame-head by keys.

Dovetail-joint.—This joint has three varieties:—1st, the common dovetail, where the dovetails are seen on each side of the angle alternately; 2d, the lapped dovetail, in which the dovetails are seen only on one side of the angle; and, 3d, the lapped and mitred dovetail, in which the joint appears externally as a common mitre-joint. The lapped and mitred joint is useful in salient angles, in finished work, but it is not so strong as the common dovetail, and therefore, in all re-entrant angles, the latter should be used.

The three varieties of dovetail-joint above enumerated are illustrated in Plate LXXI.

Fig. 1, No. 1 is an elevation of the common dovetail-joint; No. 2, a perspective representation; and No. 3, a plan of the same.

In all the figures the pins or dovetails of the one side are marked A, and those of the other side are marked B.

Fig. 2, Nos. 1, 2, 3.—In these the lap-joint is represented in plan, elevation, and perspective projection.

Fig. 3, Nos. 1, 2, 3.—In these figures the mitred dove-

tail-joint is represented in plan, elevation, and perspective projection. The dovetails of the adjoining sides are marked respectively B and C in all the figures.

Fig. 4, Nos. 1 and 2, and *Fig.* 5, Nos. 1 and 2, show the modes of dovetailing an angle, when the sides are inclined to the horizon, as in a hopper. The pins of the one side are marked A, and those of the other side B, on all the figures.

Gluing up Columns, &c.— PLATE LXXII.—*Fig.* 1, Nos. 1 to 5 show in detail the manner of framing together and gluing up the parts of a column and its entablature.

Fig. 1, No. 4 contains four quarter plans of as many courses of timber, forming the mouldings of the base; and No. 5 shows the same in elevation and section, marked with the same letters. The square plinth is first formed by taking four pieces of equal length, mitring them together at the angles, and securing them by screws and by glue, and strengthening them with blockings in the angles, as at *a*. The upper surface of this course is then planed true, and prepared to receive the next course. This course is also formed of four pieces, to form the torus, A, No. 5. These pieces cross the angles, and are joined on the middle of the length of the first pieces. The surface of this is in like manner planed true to receive the next course B; the pieces composing which have their joints on the middle of the pieces of the course below, and are glued down on them. So likewise with C. When the formation of the block is thus completed, it is turned, and the proper rebate *e* formed in the upper surface to receive the lower part of the shaft. The quadrant marked D shows a section of the lower part of the shaft. The half-plan at O O, on the right hand of *Fig.* 1, No. 3, is the upper part of the shaft. It will be observed that the shaft is built of staves, which should always have their joints in the centre of the fillet. The staves are glued together and secured by blockings *m m m*, glued in the angles. The staves should not exceed 5 inches wide, whether for columns or pilasters, and they should be as thin as is consistent with strength. It is well to work them to the taper necessary for the diminution of the columns before gluing them together.

Fig. 1, No. 3, on the left of this figure, at O O, is the half of the horizontal section of the shaft immediately below the necking at A B, *Fig.* 1, No. 1; R is a quadrant of the horizontal section at C D, and S a quadrant of the horizontal section at E E.

Fig. 1, No. 1 is the elevation of half the capital, and the architrave frieze and cornice, and No. 2 is a vertical section of the same. The framing of the architrave, frieze, and cornice does not require description; and it is only necessary to make this remark, that by using blockings, the thickness of the material in the architrave and frieze might be reduced.

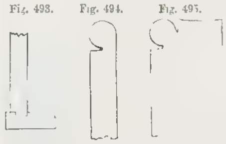
Diminution of Columns.—*Fig.* 2.—The upper diameter of a column is less than its lower diameter, but the gradual diminution between them is not made by straight but by curved lines. The usual mode of describing the curved contour of the diminution is as follows:—Let *a b* be equal to the lower diameter of the column, of which let *e f g* be the line of the axis, perpendicular to *a b; f g* the height of the column, and *r* 6 its upper diameter. On *a b* describe a semicircle, and from *r* and 6 draw lines parallel to the axis, cutting the semicircle in *s o*; divide *s a* or *o b* into any number of equal parts, the more the better, and divide the height *f g* into the same number of equal parts, as 1, 2, 3, 4, 5, 6, and through these draw lines crossing the axis perpendicularly. Then by drawing lines parallel to the axis through the corresponding divisions in the semicircle meeting these points, the curved contour of the column will be obtained, and by bending a lath, so as to pass through these points, the curve may be drawn, and the rule *c d* formed.

Fig. 3.—The same thing may be obtained in a manner somewhat different, as shown in *Fig.* 3. In this *a b* is equal to the lower, and *c d* to the upper diameter. The points in which this latter cuts the semicircle being found, the portion of the radius *x p* is divided into certain equal parts, and the height of the column *f g* into the same number of equal parts, and from the points where lines parallel to *a b*, drawn through the divisions in *x p*, meet the semicircle, other lines, parallel to the axis, are drawn, as before, to intersect the lines drawn through the divisions of the height, 1, 2, 3, 4, 5, 6.

Another method of describing the section of the column is shown in *Fig.* 4. Let *b e* be the line of the axis of the column, A *b* half of the lower diameter, and B *e* half of the upper diameter. Take in the compasses the length of the semi-diameter at the bottom, and setting one foot in the extremity of the upper diameter at B, with the other foot cross the axis at *h*, produce the lower diameter indefinitely, as A *r*; and through B, and the point *h* on the axis, draw a line cutting the line A *r* in *k*; then from *k* as a centre, draw any number of lines, as *i* 7, *m* 6, &c., and make each of them as *i* 7, equal to the lower semi-diameter. In the same figure is represented a trammel for doing the same thing as has been described. *a b e* is a right-angled rule, kept to its form by the angle-piece *c d*. In the limb *b e* is a groove, which is made to coincide with the axis of the column, and in which slides freely a stud *h*. The other arm *a b* of the rule carries a stud *k*. The rule *f g* has a groove or slot sliding on stud *k*, and its other end carries the stud which slides in *b e*. Now, it is evident that if the points *k b h g* of the trammel be adjusted in accordance with the preceding description, the point *g* will, on the rule *f g* being slid along, guided by the grooves, describe the elliptic curve A, 1, 2, 3, 4, 5, 6, 7, *g*.

Moulding is the forming the surface of the wood into various square and curved contours. In Plates LXIII., LXIV., and LXV., are examples of the classic mouldings, and in LXV.[a] some of the Gothic mouldings have been given. It is only therefore necessary here to observe that the *bead* is of constant occurrence in joiner-work, and under one or other of the conditions following. When the edge of a piece of wood is reduced to a semi-cylindrical form, as in Fig. 493, it is said to be rounded. When the rounding forms more than a semicircle, and there is a sinking on the face, as in Fig. 494, the rounding is termed a *quirk-bead*, the groove or sinking being termed the *quirk*. When the edge is rounded with a sinking or groove on both faces, as in Fig. 495, the moulding is a double-quirk bead.

Fig. 493. Fig. 494. Fig. 495.



When any moulding is formed on the edge of a piece of framing it is said to be *stuck*. When it is formed on a separate piece of wood, and attached to the part of the

GLUEING UP COLUMNS &c.

Fig. 1. Nº 1 Fig. 1. Nº 2

Elevation and Section of Capital & Entablature.

Fig. 2 Fig. 3

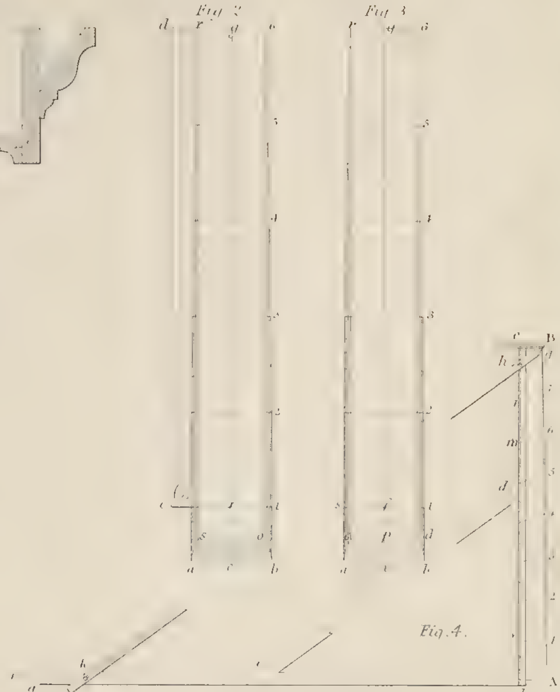
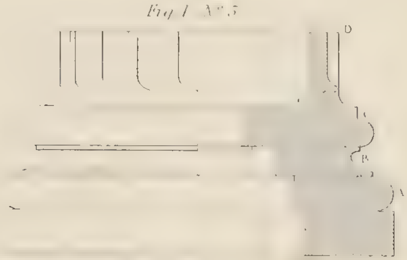


Fig. 4.

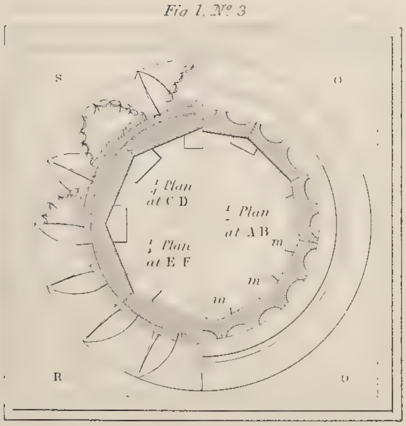
Trammel for diminishing Columns

Fig. 1. Nº 5



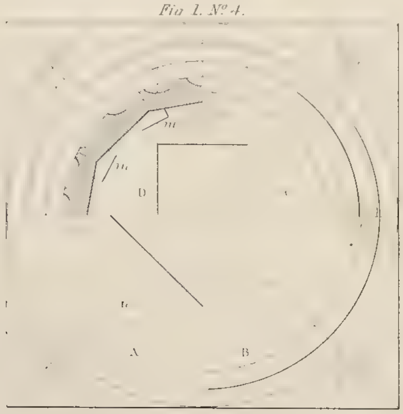
Elevation and Section of Base of Column

Fig. 1. Nº 3



Plan of Capital.

Fig. 1. Nº 4.



Plan of Base

A F Oridge delᵗ J W Lowry fc.

Inches 12 6 0 1 2 3 Feet

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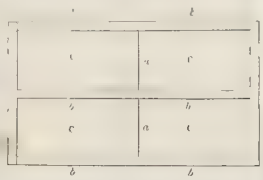
framing it is meant to ornament, it is said to be *laid in*, or *planted*.

The modes of joining timber above described are all more or less imperfect. The liability of wood to shrink renders it essential that the joiner should use it in such narrow widths as to prevent this tendency marring the appearance of his work; and, as even when so used it will still expand and contract, provision should be made to admit of this. The groove-and-tongue joint admits of a certain amount of variation, and the grooved, tongued, and beaded joint admits of this variation with a degree of concealment, but the most perfect mode of satisfying both conditions is by the use of framed work.

Framing in joinery consists of pieces of wood of the same thickness, nailed together so as to inclose a space or spaces. These spaces are filled in with boards of a less thickness, termed *panels*.

In Fig. 496, *a a*, *b b* shows the framing, and *c c* the panels. The vertical pieces of the framing *a a* are termed *styles*, and the horizontal pieces *b b* are termed *rails*. The rails have tenons which are let into mortises in the styles. The inner edges of both styles and rails are grooved to receive the edges of the panels, and thus the panel is at liberty to expand and contract. Framing is always used for the better description of work. The panels should be formed of narrow pieces glued together, with the grain reversed alternately. They should never exceed 15 inches wide, and 4 feet long. These dimensions, indeed, are extremes which should be avoided.

Fig. 496.



The panels may be boards of equal thickness throughout, in which case the grooves in the styles and rails are made of sufficient width to admit their edges, as in Fig. 497. These are termed *flat* panels. *Flush* panels, again, have one of their faces in the same plane as the face of the framing, and are rebated round the edges until a tongue sufficient to fit the groove is left. *Raised* panels are those of which the thickness is such that one of their surfaces is a little below the framing, but at a certain distance from the inner edge, all round it, begins to diminish in thickness to the edge, which is thinned off to enter the groove. The line at which the diminution takes place is marked either by a square sinking or a moulding. All these kinds of panels are sometimes combined.

Flush panel framing has generally a simple bead stuck on its edges all round the panel, and the work is called *bead flush*. But in inferior work the bead is run on the edges of the panels in the direction of the grain only, that is, on the two sides of each panel, while its two ends are left plain; this is termed *bead butt*. The nomenclature, however, of the various descriptions of framed, and of framed and moulded work, will be best understood by reference to the annexed figures. Fig. 497 is the flat panel. In this the framing is not moulded, and is termed *square*. In Fig. 498 the same framing is shown with a moulding stuck on it. In Fig. 499 the same framing is shown with a moulding *laid in* or *planted* on each side. Mouldings which, like these, project beyond the surface of the framing, are termed *Bolection mouldings*. In Fig. 500 a *bead flush* panel is represented. In Fig. 501 a bead and flush panel with moulding laid in. Fig. 502 shows a *bead butt* panel. Fig. 503 a raised panel with stuck mouldings; and Fig. 504 a panel *raised* on one side with *stuck mouldings* and *bead* and *flush* on the other. Panels in external work, such as doors, may be secured against being cut through by depredators, by boring holes across them from edge to edge, and inserting iron wires, or by crossing them diamond fashion with thin hoop iron, nailed on the inside.

Fig. 497

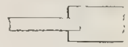


Fig. 498

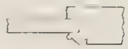


Fig. 499

Fig. 500

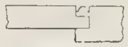


Fig. 501

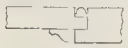


Fig. 502.

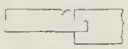


Fig. 503

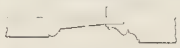
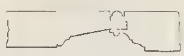


Fig. 504.



In Plate LXV. a great variety of mouldings for framed work is given, and the use of them will now be better understood. The four last examples on that plate are different from all the others, as the groove for the panel is made in the moulding, which is framed and mitred.

When the labours of the mason, bricklayer, carpenter, &c., have prepared the carcass of the building, it is ready for the operations of the joiner; but, as almost all his work is previously prepared in his workshop, he has little more to do in the building itself than fitting and fixing. His first operation in the building is to cut out the bond timbers from the openings, and to fill them in with old sashes, or with oiled paper on frames. He next prepares the joists for the flooring boards, by trying them with straight edges, reducing inequalities with the adze, and filling up hollows with pieces of wood termed *firrings*. Previous to laying the flooring boards, the pugging is put into its place, the boards are then prepared for laying, and turned over, face downwards, until the plastering is completed. The grounds for the various finishings are now fixed, to serve as gauges for the plasterer, and the staff beads are set; and, on this being done, the operations of the joiner should be suspended until the plastering is finished.

The *grounds* consist of pieces of wood projecting from the naked of the wall to the face of the plastering; they are put round doors, windows, and other openings, to attach the architraves or other finishings to, and are also fixed wherever skirtings or linings require to be attached. In Fig. 507, *c*, *c*, shows the framed ground of a window, and B, in Fig. 508, the narrow ground for skirting. The skirting grounds are generally dovetailed at the angles, and they require to be well blocked out to the range, and firmly fixed.

Floors are laid in two ways, called *folded* and *straight joint*. In folded floors, the boards are plain-jointed, and one of them being firmly fixed in its place, at the extremity of the floor, and another parallel to it, at a distance apart nearly equal to the aggregate width of three or four boards, these intermediate boards are then put into this space, and forced down and nailed. In this mode all the heading joints of these boards, thus laid at once, neces-

sarily occur on the same joist, and as, for obvious reasons it is important to break joint, this of itself is enough to condemn the practice. In straight-joint floors, the boards may be plain-jointed or dowelled, or grooved and tongued. Each board is laid separately; every heading joint is made to fall on a joist, and is broken or covered by the adjoining board. The heading joints are also grooved and tongued. The boards are brought close together by gentle driving, or by the use of a flooring cramp, and they are nailed either through the face or edge. When nailed through the face, flooring brads, a kind of nail having only a projection on one side, instead of a head, are used, and are punched in below the surface, so as to admit of the boarding being dressed off with the hand plane after it is laid. For side or edge nailing, clasp nails are used.

If the flooring boards are not gauged to a thickness, they require the following preparation before they are laid. Their edges are gauged to a thickness by a rebate plane; they are then laid with their face down in the position they are to occupy, and are cut down with an adze, at the place of every joist, to the gauge mark, so that the boards form a level surface when turned into their places. From the use of machinery now in gauging flooring boards, the operation above described has rarely to be performed.

Skirting.—The boards with which the walls of a room are finished next to the floor, or, in other words, the plinth, is termed the skirting. When it consists simply of a board, moulded on its upper edge, it is still termed the skirting; but if the plinth is made up of more than one piece, the plain board, next the floor, is termed the *skirting board*, and the upper part the *base mouldings.*

In the better description of work, the skirting board is let into a groove formed in the floor to receive it, and is supported behind by vertical pieces or blockings, fixed at frequent intervals, between the narrow grounds and the floor. Sometimes, however, the skirting, in place of being let into a groove, has a fillet nailed along the floor behind it as a stop, and if its depth be not great, and the wood strong enough, no blockings are used. In fixing the skirting, the operation of scribing is performed, to accommodate the outline of its lower edge to any inequalities which may exist on the surface of the floor.

Scribing is thus performed:—The skirting board, having its upper edge worked, moulded, or otherwise, with perfect precision, is applied to its place, with its lower edge either touching the floor or supported at a convenient distance above it, and so arranged by propping it up at one end or the other that its upper edge is perfectly level. Then to mark on its lower edge a line that will perfectly coincide with any irregularity which may exist in the floor, a pair of strong compasses is taken and opened to the greatest distance that the lowest edge of the skirting is from the floor throughout its length. The outer point of the compasses is then drawn along the floor, and the other point pressed against the skirting board, so as to mark a line which will, of course, be exactly parallel to the surface of the floor; and the board is cut to this line, either by the saw or the hatchet, It is, of course, essential that all the upper edges of all the skirting boards of the room or apartment should be adjusted to the same level line when this scribing is done.

DOORS.

Plates LXXIII.—LXXV.

Doors are either *ledged* or *framed.* Ledged or *barred* doors, as they are also called, are formed of plain boards united by groove and tongue joints, and having two or more bars or ledges nailed across them on one side to hold them together.

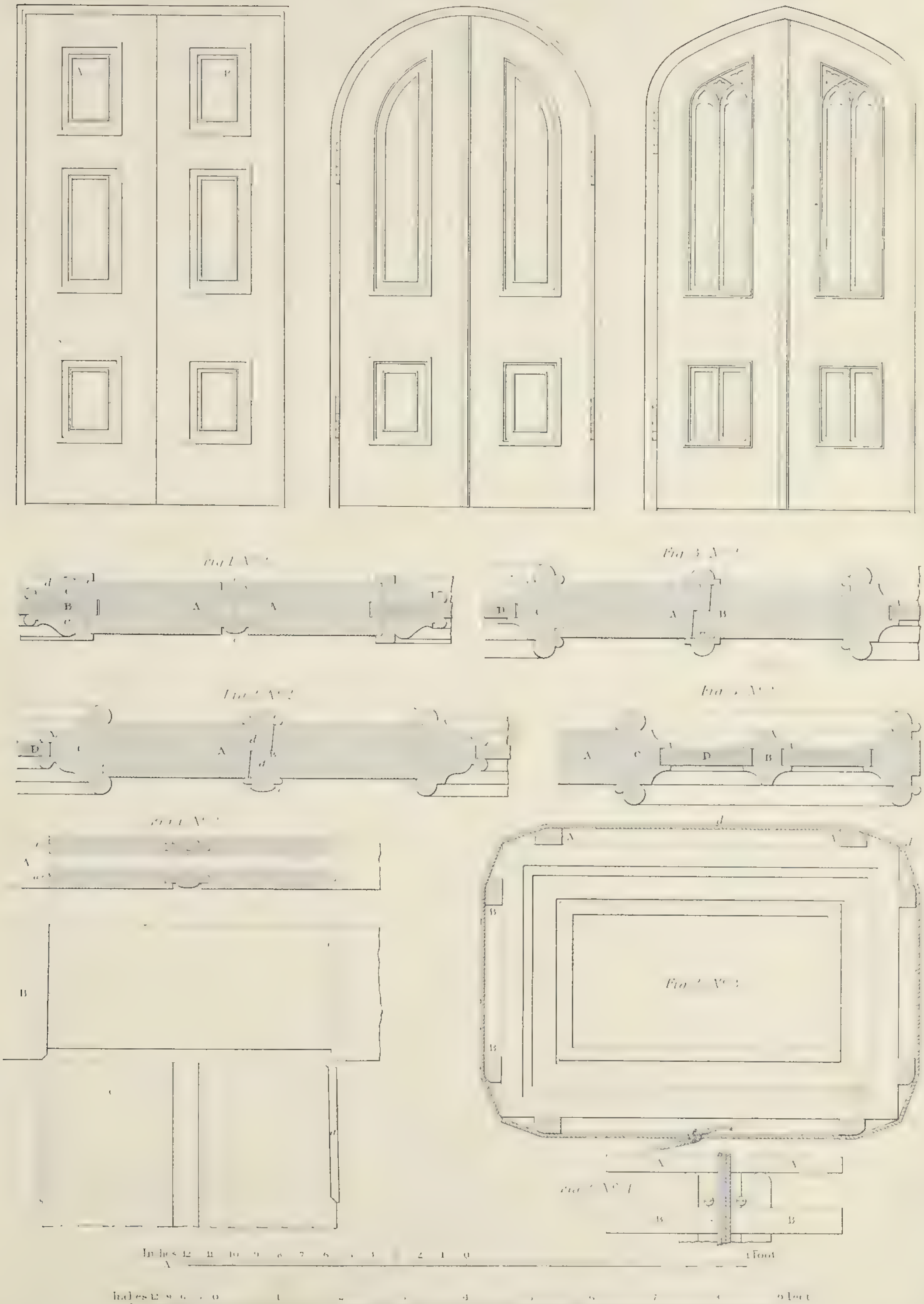
Framed doors, or, as they are termed in Scotland, *bound* doors, are of various kinds. In the framing of doors, as in other framing, the vertical pieces are termed *styles* and the horizontal pieces *rails.* When a centre vertical piece is tenoned into mortises formed in the rails it is called a *muntin, montant,* or *mounting.* The rail next below the top rail is called the *frieze* rail, and that next above the bottom rail the *lock* rail; any other intermediate rails have no specific name. In like manner the panels are named *frieze* panels, *middle* panels, and *bottom* panels. In ordinary framed doors the top and frieze rails are generally of the same width as the styles, the bottom and lock rails generally twice as wide. In Fig. 506 *a a* are styles, *b* the montant, *c* bottom rail, *d* lock rail, *e* frieze rail, *f* top rail, *g* frieze panel, *h* middle panel, *k* bottom panel.

When a doorway is closed by two doors of equal width hinged to its opposite jambs, the middle or meeting styles are frequently rebated and beaded; such a door is termed a *doubled margined* door or *two-leaved* door. Doors also, which, whilst they are in one width are framed with a wide style in the middle, beaded in the centre in imitation of the two styles of a two-leaved door, are also called double-margined doors. Fig. 505 shows the appearance of the two-leaved and double-margined doors. A *sash* door is one which is glazed above the lock rail. A *jib* door is one which is flush with the surface of the wall of the apartment in which it is placed; it has no architraves or other ornamental border, but is crossed by the skirting surbase and other finishings of the apartment, and is otherwise so finished as to be undistinguishable from the wall itself.

Plate LXXV. *Fig.* 1, No. 1, is the elevation of a double-margined door. No. 2 is an enlarged horizontal section in the line A B of No. 1. A A is the double-margined style, formed by the two styles A A, *e e* the centre bead, B the panel, *c c* the moulding laid in. The dotted lines show the manner in which the styles are forked on the top and bottom rails, which is also represented in detail in *Fig.* 1, No. 3, where B is an elevation of part of the top rail, thinned to enter the fork of the styles, and

DOORS.

DOUBLE MARGINED DOORS



White del^t

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DOORS.

SLIDING AND OTHER DOORS.

Scale to Figs 1 2 and 3

2 6 0 1 2 3 4 5 6 7 8 9 10 11

C part of the style in elevation, and A is the plan at the end of the styles, showing the fork, the thinning of the rail, and the keys *a a*.

Fig. 2, No. 1, is a two-leaved or double-margined door, and *Fig.* 2, No. 2, a section through the meeting styles A, B, showing the rebates *d d*, and beads *e e*, which in this case are planted on. The panel D is let into a groove in the moulding C, in the French manner already noticed, and the moulding is framed and united in the manner shown in *Fig.* 2, No. 3 and No. 4.

Fig. 3, No. 1, is a double-margined gothic door. *Fig.* 3, No. 2, is an enlarged section through the meeting styles showing the rebates A B, the panels D, and the panel moulding C, framed as in the last example. *Fig.* 3, No. 3, is an enlarged section through one of the panels, A style, B centre rib, C moulding, D panel.

PLATE LXXIV., *Fig.* 1, is the elevation of a double-margined door of large dimensions, such as a folding-door used to close the communication between two drawing-rooms. But the door here illustrated, in place of folding, is made to slide into recesses in the wall or partition. *Fig.* 2 shows the plan of the doors and recesses, and *Fig.* 3 is a vertical section through the recessed part of the partition and the door. *Fig.* 4 is a section to an enlarged scale showing the top rail of the door, the recess in the partition, one of the pullies and the straps by which the door is hung to it, and the iron bar on which the pullies run. *Figs.* 5 to 13 are examples of French doors, showing many varieties of panelling and ornamentation.

PLATE LXXIII., *Fig.* 1, is the elevation of a jib door in the side of an apartment which has a base *b*, dado and dado moulding *a*; and *Fig.* 3 is a vertical section through the door. In *Fig.* 2 is drawn to a larger scale a horizontal section through part of the hanging style of the jib door and the frame in which it is hung. The dotted lines show the line of the hinging through the base mouldings, and the extent to which the door can be opened. *Fig.* 4 is a section through the dado moulding, and *Fig.* 5 a section through the skirting and base moulding, both to the same enlarged scale as *Fig.* 2.

Fig. 6 is an elevation of a pew door; and *Fig.* 7 a section through its hanging style and the style of the framing to which it is hung. It will be seen that it is treated precisely as a jib door.

The jambs of doorways are finished with wooden linings which are either plain or framed, and moulded to correspond with the door; they are in either case fixed to the grounds, and if the jamb be wide the lining may require backings or cross pieces to stiffen them. The doors are hung in their places in two ways. In the first a door frame is set in the wall or partition; to this the door is hinged, and the linings being kept back from the edge of the frame to a distance equal to the thickness of the door, thus form the rebate to receive the door and the stop against which it shuts. In the second mode the lining covers the whole of the jamb, and is rebated to form the recess to receive the door, and a corresponding rebate is formed on the other edge of the lining for appearance sake.

Doorways are in general surrounded by an ornamental wooden margin or border, not merely, however, for ornament, but especially to cover the junction between the plaster and wooden ground in the case of a wall, or between the plaster and door frame in the case of a partition. These margins are sometimes plates of wood ornamented with mouldings, and are termed architraves, examples of which are given in PLATE LXIX., or they may consist of pillars or pilasters with proper entablature. The pilasters are set on solid blocks of the same height as the skirting, and so also are the architraves in good work; but in other cases they run down and are scribed to the floor. It is said above that the chief use of the architrave is to cover the joint between the wooden ground or the door frame and the plaster. The ground being fixed and the door frame set in its place, serve as guides for floating the plaster by, and when the plaster is dry the architrave should be applied so as to lap over the joint and effectually cover it; but in ignorance of good construction it is common to fix the architraves before the plastering is complete, a practice which cannot be too severely reprehended.

WINDOWS, AND FINISHINGS OF WINDOWS.

PLATES LXXVI.—LXXVIII.

Windows consist of the glazed frames called *sashes*, and of the frames or cases of various kinds which contain these. The sashes may be either fixed, or hinged to open like a door, or suspended by lines over pullies and balanced by weights.

The frame for the fixed sash consists of solid sides or styles, a head piece or lintel, and a sill, which is made wider than the other pieces and weathered. This frame is rebated to receive the sash, and the latter is retained in its place by a slip of wood nailed round the inside of the frame.

The *hinged* or *French* sashes, as they are termed, have rebated solid frames, and in their construction every care is required to make them weather tight at the sills and where they meet in the middle. In exposed places they should always be made to open outwards, as the effect of wind is then to close them and make their joints tighter.

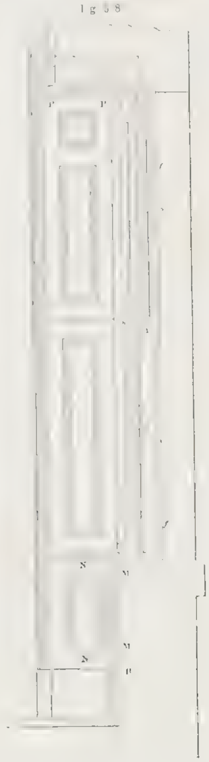
Suspended sashes are hung on frames provided with boxes or cases to contain the balancing weights. In order that the reader may become familiarized with the several parts of the sash-window, its frame, its shutters, and finishings, sketches are here presented of the horizontal and vertical sections through a window, and these being described and a notion of them acquired, it will not be necessary to embarrass him with repetitions of the description of the same details in the plates.

Fig. 507 shows a horizontal section, and Fig. 508 a vertical section of the window frame. The frame consists of sides or breasts of about $1\frac{1}{2}$ inch thick, grooved down the middle for the reception of a beaded piece *o o* (Fig. 508), called a parting bead, from its serving to part the sashes. The sides or breasts are called the pulley styles, and the frame is completed by the sill below and the lintel above. To the outside edge of the pulley style the beaded pieces *f f* forming the sides of the casing or boxing are attached, and the beaded edge projects so far beyond the face of the style as, with the parting bead, to form the outer path or channel in which the sash slides. On the inner edge of the pulley style is fixed the piece *b b* (Fig. 507), called the inside lining, to which the shutters are hinged; a back piece extending between the inside lining and outside piece *f*, parallel to the pulley style, is added, to complete the case or boxing, and the box has sometimes, and should always

have, a division in the centre to separate the weights of the upper and lower sashes. The path for the inner sash is formed by a slip or stop bead, fixed to the styles by nails or, preferably, by screws. In the lower end of the path of the outer sash a hole is cut in the pulley style sufficiently large to admit the weights, so that the sashes may be hung after the frames are fixed, and the lines repaired at any time. This is called the pocket, and it is covered by a piece of wood attached by screws.

The sashes themselves consist of an outer frame, which is composed of styles and rails. The bottom rail of the lower sash is deeper than the others, and is throated to prevent the water from driving under it. The meeting rails of the upper and lower sashes are made wider than the others and fit together in

Fig. 508.



the manner shown by A, Fig. 508. The horizontal and vertical bars, which divide the sashes into panes, are termed *sash bars.* The vertical bars, like the styles in framing, extend, in single pieces, between the rails of the sash, the horizontal bars being cut to fit their places, and dowelled together through the vertical bars.

The fittings of a window consist of the boxings for the shutters, if there be any, the linings, the shutters, with their back flaps, and the architraves, or other finishings of the opening in the apartment. All these parts are exhibited in Fig. 507 in horizontal section. The boxings are formed in the space between the inside lining of the sash frame and the framed ground. The back of the recess is sometimes plastered; but, in better works, it is covered with a framed lining, as at *a* in the Fig. 507, called a back lining. This has generally bead and flush panels, and is fitted in between the inside lining *b*, and the framed ground *c*, and is generally tongued into both. The shutters *d*, are framed as doors, and panelled and moulded in the same manner. They are hinged to the inside lining. The back flaps are generally lighter than the shutters, and are sometimes framed and moulded, so that the whole exposed surface shall present the same appearance when the shutters are closed; but they more frequently consist of bead and flush framing. The shutters in place of being hinged, are sometimes suspended and balanced by weights, like the sashes.

The wood work M M, Fig. 508, which extends from the window sill to the skirting, is called the *breast* lining; and that on the side of the recess, extending from the bottom of the shutters to the skirting, the *elbow* lining. The ceiling of the window recess P P is also formed of wood, and is termed the *soffit* lining. These linings are all framed and moulded to correspond with the doors and other framed work of the room. The margin of the window opening is finished with architraves or other ornamental appliances, in the same manner as the doors.

PLATE LXXVI.—*Fig.* 1, No 1, is the elevation of a sashed window with its finishings. Immediately under No. 1 is an enlarged section of one of the jambs of the window, showing in detail the lower sash, the pulley piece, boxing, weights, shutter boxing, back lining, architrave and shutters. *Fig.* 1, No. 3, is a vertical section to the same enlarged scale, through the lower part of the window and the window breast, showing the rail of the lower sash, the sill of the window frame, the breast lining and skirting.

The upper part of the window is shown in *Fig.* 1, No. 3, at the bottom of the plate. It shows the rail of the upper sash, the lintel of the window frame, the soffit lining, and the architrave.

Fig. 1, No. 4, is a section through the meeting rails of the upper and lower sashes, showing the nature of the rebate, or check, as it is called in Scotland.

Fig. 2, No. 1, is a sashed window double-margined, in imitation of a French window.

Fig. 2, No. 2, shows the details, on a larger scale, of the shutters, which are so arranged as to form the pilasters at the sides of the opening in the apartment. *Fig.* 2, No. 3, is a section through the top of the window, showing the details of the entablature over the pilasters; and *Fig.* 2, No. 4, is a section through the centre style of the sash.

A sash bar, full size, is shown in section on the left-hand side of the plate.

PLATE LXXVII.—*Fig.* 1 shows part of the elevation, and *Fig.* 2 part of the plan of a window on an irregular octagonal plan. In this the shutter of the widest part of the window sinks into the breast and is suspended over pullies, and balanced by weights like the sashes. *Fig.* 3 shows the manner of attaching the suspending lines by means of a bracket carried below the bottom of the shutter, so that the pulley and weights may be entirely contained in the window breast. *Fig.* 4 is a plan or horizontal section through the breast; and *Fig.* 5 is a vertical section of the same.

The shutters of the side windows are hinged to the frame in the usual way, as seen in *Fig.* 2, which represents a horizontal section of the window above the sill, with the shutters closed.

Fig. 6 is a section of a sash bar, full size.

PLATE LXXVIII.—*Fig.* 1 shows the finishing of a window, looking upwards towards the soffit. The dotted lines A B show the shutters and back flap when closed;

FINISHINGS OF WINDOWS.

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FINISHINGS OF WINDOWS.

Fig 1

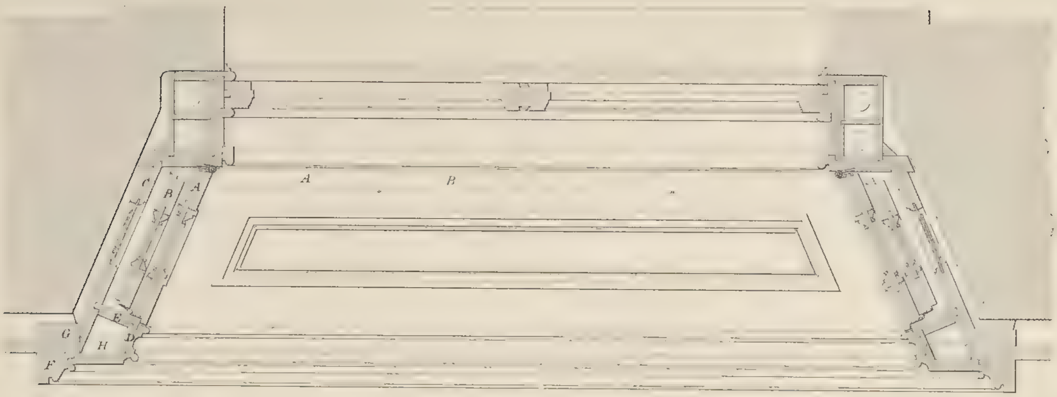


Fig 2

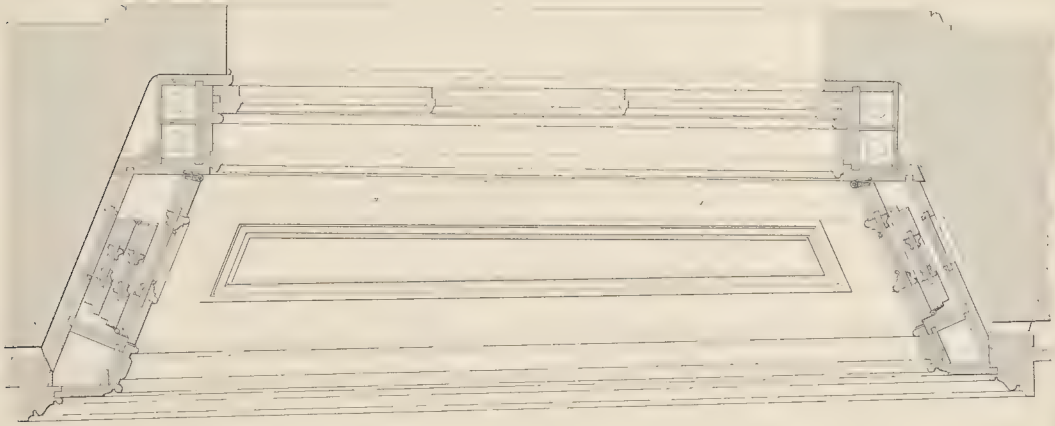
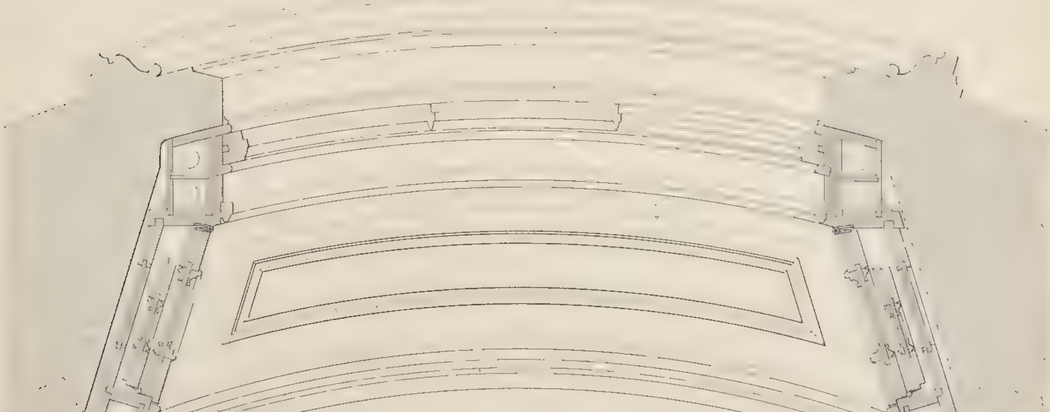


Fig 3

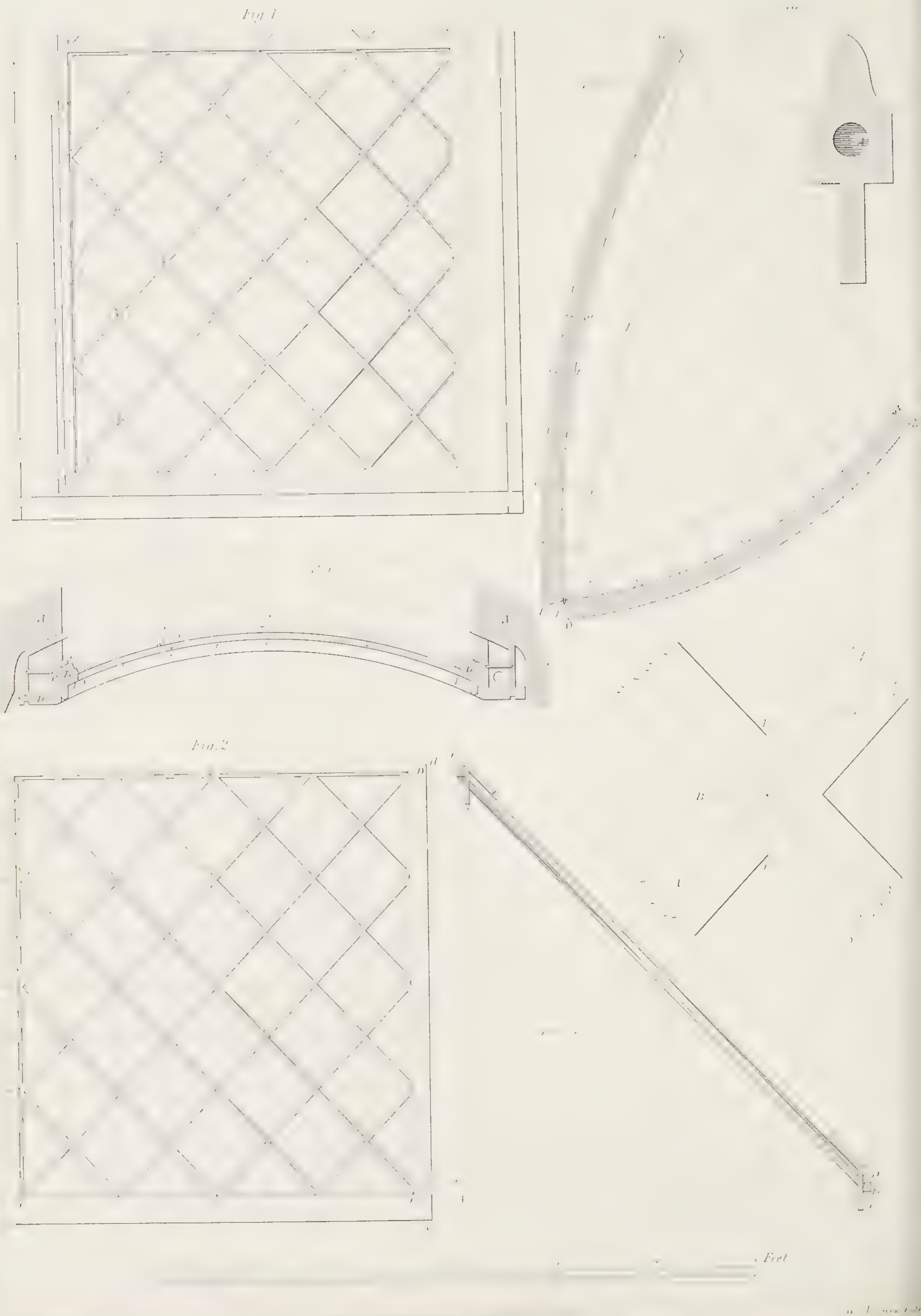


12 9 6 3 1 1 2 3 4 5 Feet

I White del. W. A Beever Sc

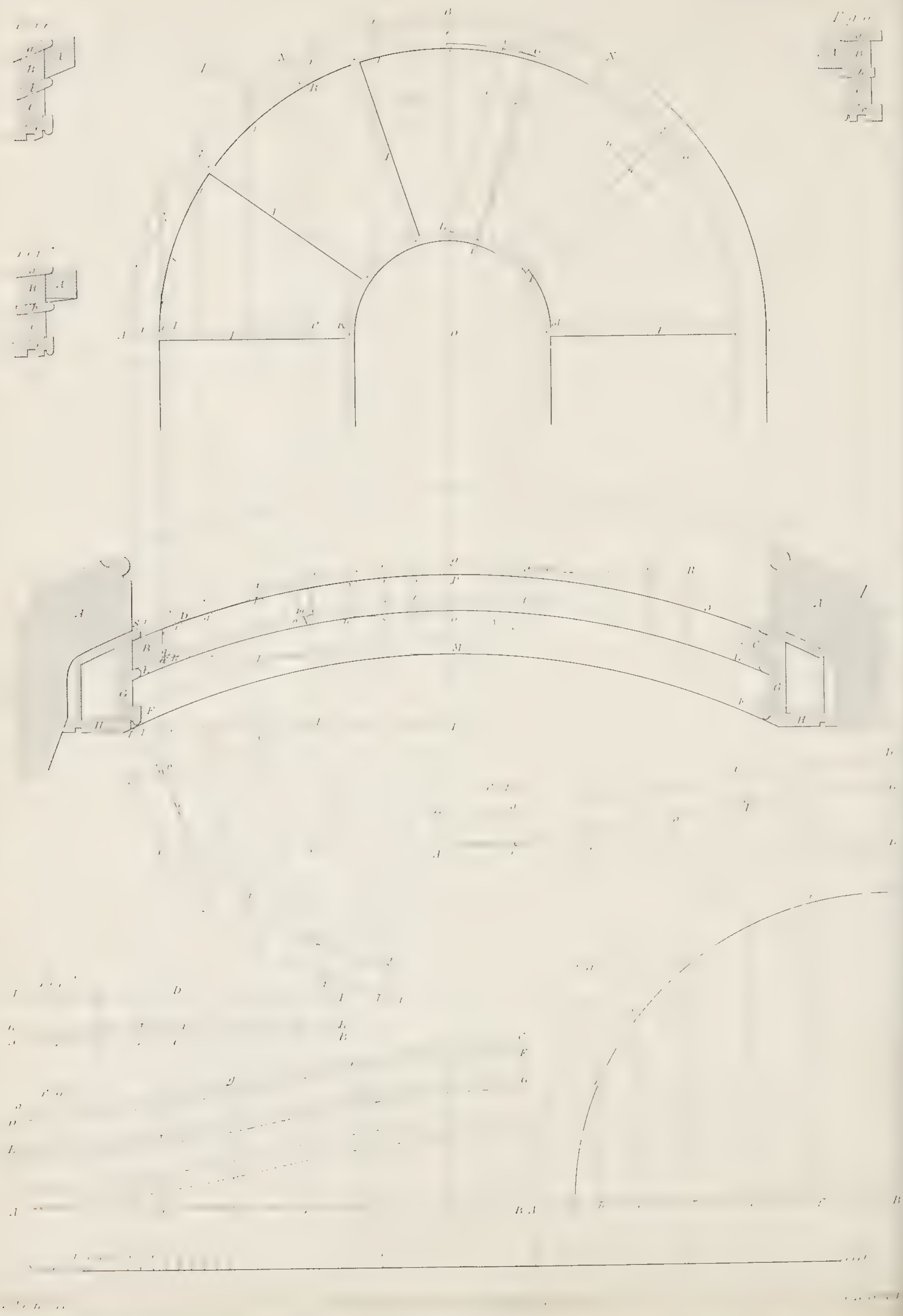
FINISHINGS OF WINDOWS.

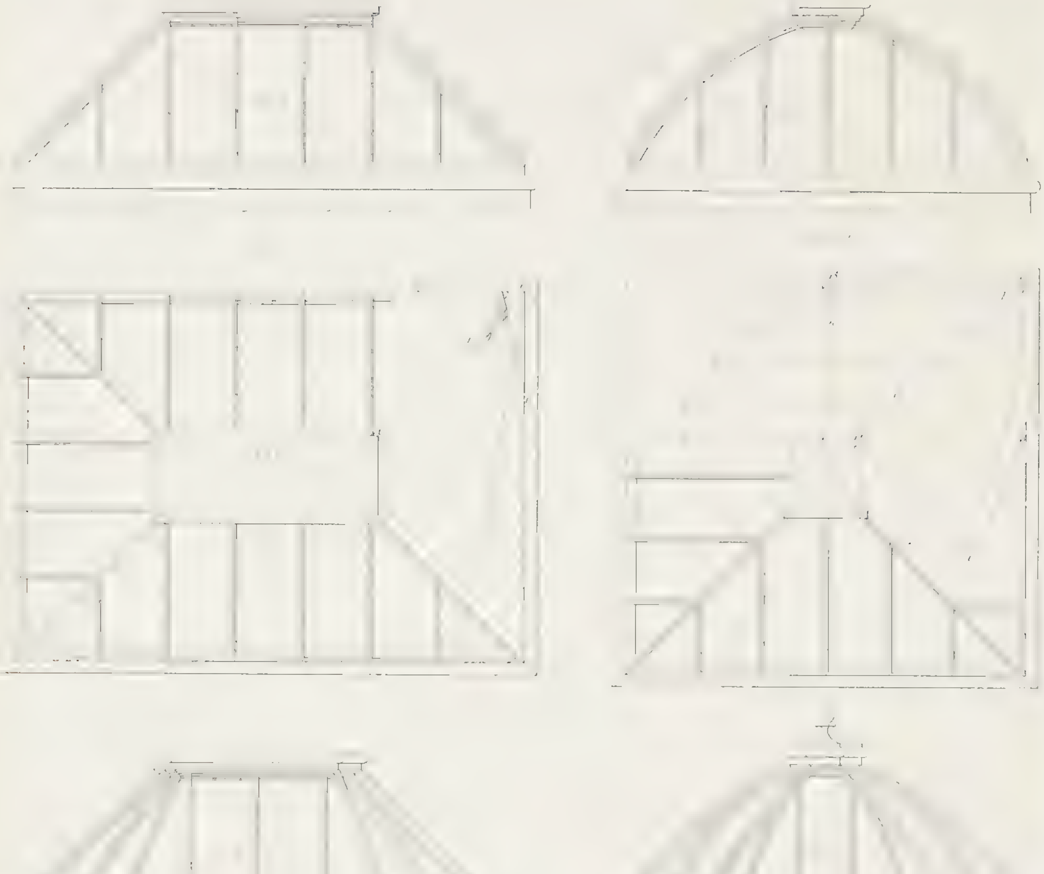
PLATE LXXVII.

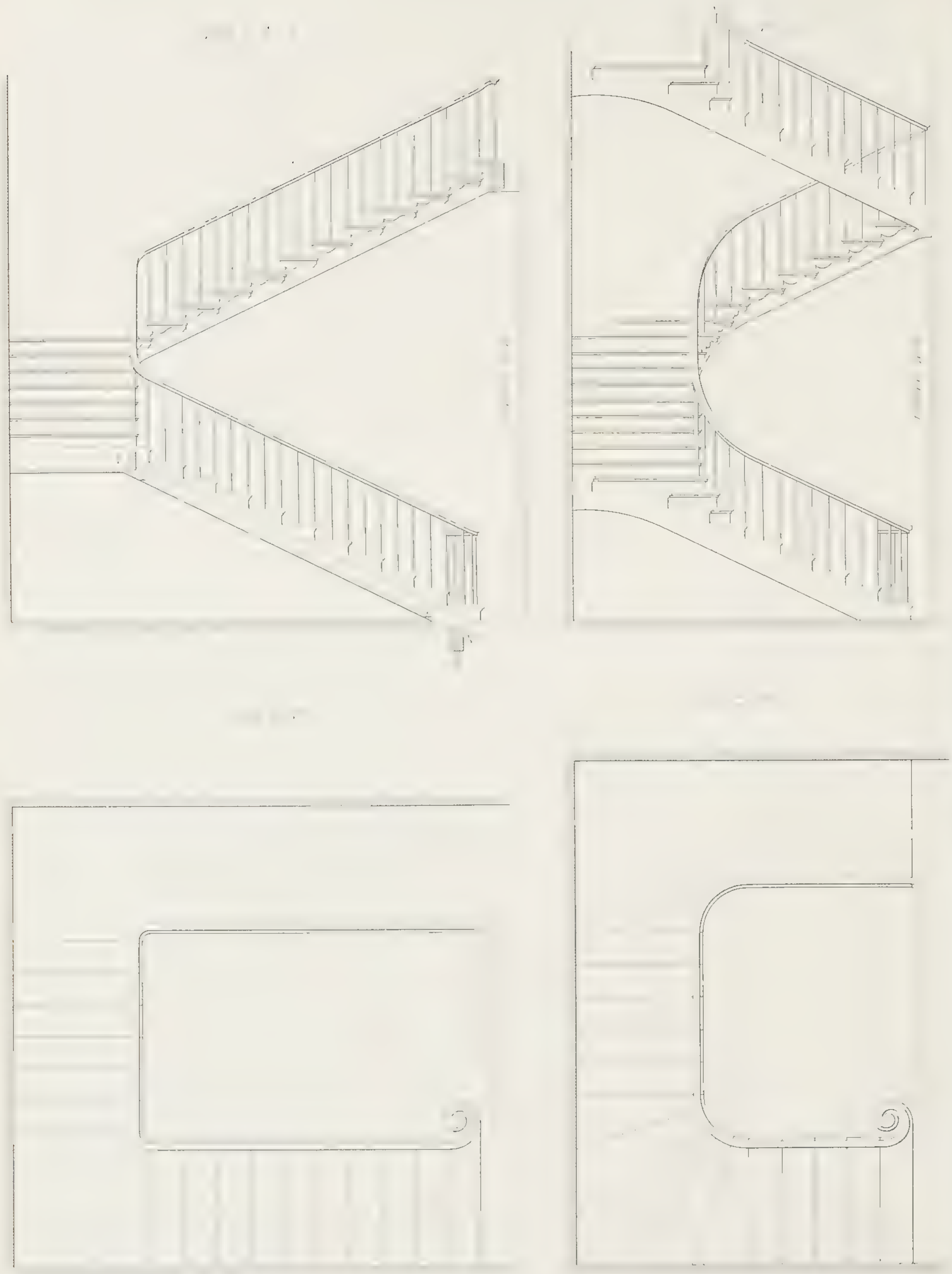


J. White del.

CIRCULAR WINDOW

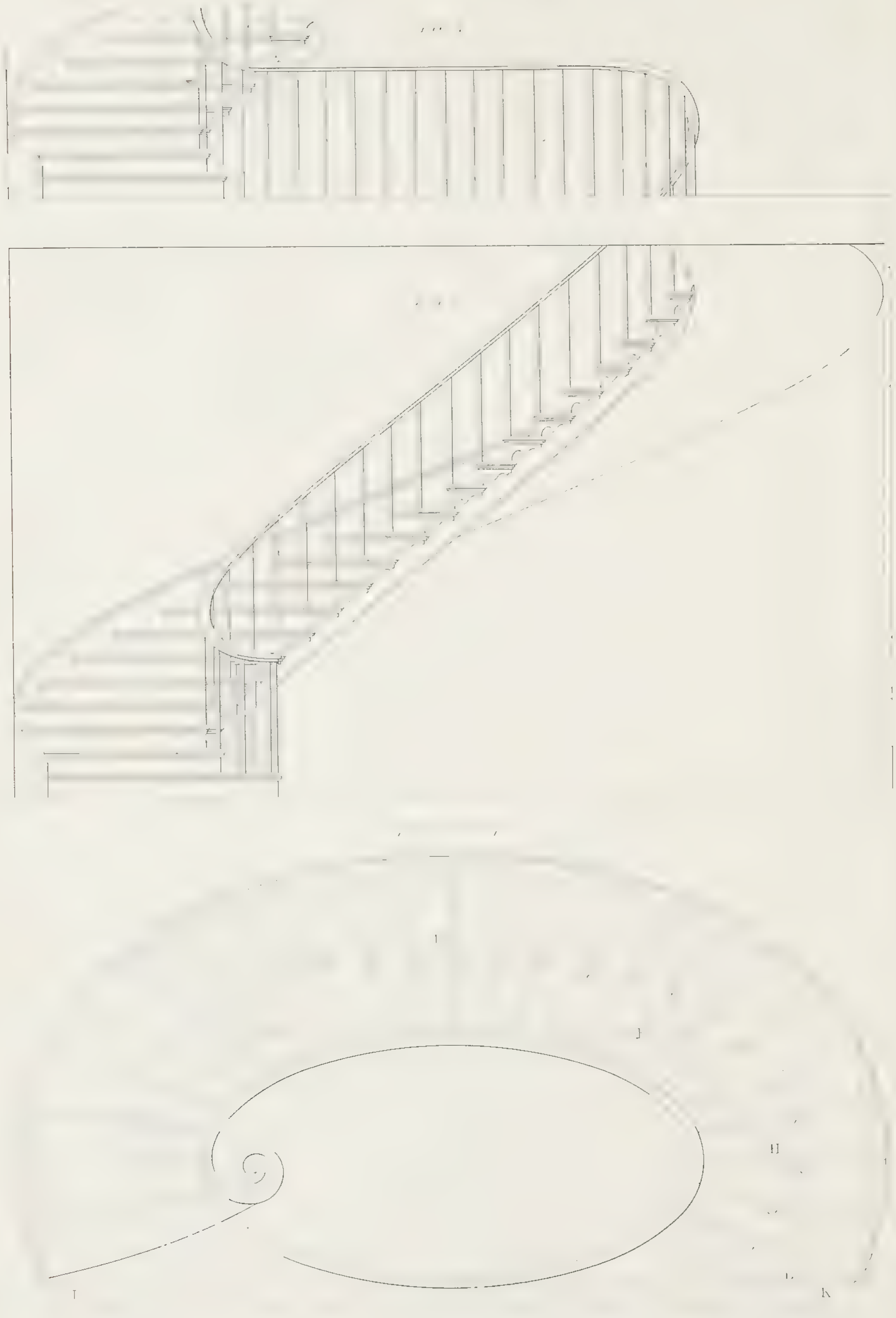






STAIRS

GEOMETRICAL STAIRS, ELLIPTICAL PLAN



STAIRS

CARRIAGES OF ELLIPTICAL STAIRS, AND DETAILS

and the shaded parts, A B, the shutter and back flap when folded into its boxing; C H D E is the boxing and back lining; G the ground; and F the architrave.

Fig. 2 shows the soffit, the shutters, and finishings of a window in a wall thicker at one side than the other; the drawings are so detailed as to be self-explanatory.

Fig. 3, the soffit, shutters, and finishings of a window in a circular wall.

CIRCULAR WINDOW.

Plates LXXIX, LXXX.

Plate LXXIX., *Fig.* 1, No. 1, is the plan, and No. 2, part of the elevation of a circular window, with diamond formed panes.

In No. 1, A are the jambs, B the sash, C the pulley style, E F the window sill, D the inside lining. The centre lines of the divisions for the panes are set out on the plan of the lower rail of the sash, at *c d e f*; the thickness of the bars at *a b*, *k l*, *o*, &c.; and the sites of the crossings or intersections of the bars at *h i*, *n*, &c. The heights are set out in a similar manner on No. 2, and from these data the elevation can be drawn, as in the manner already familiar to the reader. *Fig.* 2 is an elevation of the lower sash on the stretch-out; and *Fig.* 3 the stretch-out of the diagonal bar A D, showing the twist occasioned by the curvature.

To find the mould for the curvature of the diagonal sash-bar.—In *Fig.* 4, let A B E D be the plan of the bottom rail, and let it be divided into any number of equal parts —1, 2, 3, 4, &c. Through these draw ordinates at right angles to the chord line A B, meeting it in *a b c d*, and produced beyond it to meet the chord line A C of the diagonal bar in *l m n o p*. Through these points of intersection draw ordinates perpendicular to A C, and make them equal to the corresponding ordinates of A B, as *l q v* to *a f* 1, *m r w* to *b g* 2, &c.

Fig. 5 shows the section of a sash bar, full size, with a dowel hole A; and underneath is shown the mitring of the bars B D C E, and the dowel A A, all full size.

Plate LXXX.—The figures in this plate illustrate the framing of a circular headed sash in a circular wall.

Fig. 1, No. 1, is a plan of the window, and No. 2 an elevation of the circular headed sash. In No. 1, A A are the jambs, S the outside lining, B C the upper sash, G G the pulley styles, H the inside lining, E the parting bead, F the stop bead, or batten rod, as it is sometimes called, M the sill.

To find the veneer for the arch-bar K L M *called the cot-bar, or chord-bar.*—Set out the stretch-out of the arc K L M, *Fig.* 1, on the line A B, *Fig.* 4, and draw lines from the divisions in the arc to any chord line, as N *o*, No. 1; then make the ordinate C *a* D, *Fig.* 4, equal to *o z* P, No. 1, 3 *b e* equal to *r t y*, and so on; then G E D F H, *Fig.* 4, will be the veneer for the arch-bar.

To find the mould for the radial bars.—From P in No. 1 draw P R a tangent to the curve; and on it draw lines from division *l* in the radial bars F H E G, and produce them to cross the plan of the lower sash; then transfer the ordinates R *h i*, *j k l*, &c. to H *r s*, 3 *t u*, and the ordinates of the bars in No. 2, and the moulds L G F *s* of the bars E G F H will be obtained.

To find the face mould for the circular outside lining.—The dotted line *a k l m n o p*, *Fig.* 1, No. 2, shows the lower edge of the lining; and lines drawn through these points perpendicular to A C, cut the line S *g* (No. 1), in *a b c d e f g*. Transfer these on the stretch-out to the line A B, *Fig.* 5, and draw ordinates perpendicular to A B, on which set up the corresponding heights from No. 2, as *b k* to *b g*, *c l* to *c h*, *d m* to *d k*, &c.

To obtain the moulds for the head of the sash frame apply the stretch-out of the outside of the arch in No. 2 to the base line A B in *Fig.* 2, and set out on the ordinates drawn through the divisions, the corresponding ordinates from the chord I K in No. 1.

To obtain the mould for the underside of the sash, *Fig.* 3, set out the divisions of the underside of the arch in *Fig.* 1, No. 2, along the base line A B in *Fig.* 3, and proceed in the same manner as above, but setting out the ordinates from the chord line L M.

Fig. 1, No. 3, shows the first division of the sash frame A N in No. 2, and the plan No. 1; the thickness of stuff required to work it out of the solid is shown at E N. The joint at N, No. 2, and *k h*, No. 3, is shown at *b c* in *Fig.* 2, and C F in *Fig.* 3.

Figs. 6, 7, and 8, are sections through the sash frame and sash at three points: 1st, above the springing; 2d, at *f*; and 3d, at the centre. The part corresponding to the pulley style is now divided into two pieces, B and C, and the parting bead *b* is inserted between them. *a* is the outer, and *c* the inner lining. The latter beaded and grooved for the reception of the soffit lining. A is the sash.

SKYLIGHTS.

Plates LXXXI.—LXXXIII.

Plate LXXXI., *Fig.* 1.—In the skylight, of which No. 1 is the plan, and No. 2 the elevation, it is required to find the length and backing of the hip.

Let A B be the seat of the hip; erect the perpendicular A C, and make it equal to the vertical height of the skylight, and draw B C, which is the line of the underside of the hip; the dotted line *g h* shows its upper side.

To find the backing, from any point in B C, as *n*: draw perpendicular to B C, a line *n* F meeting A B in F, and through F draw a line at right angles to A B, meeting the sides of the skylight in D and E. Then from F as a centre, and with F *n* as radius, cut the line A B in *m*, and join D *m*, E *m*. The angle D *m* E is the backing of the hip, and the bevel *k m l* will give the angle of backing when applied to the perpendicular side of the hip bar.

In *Fig.* 2, in which No. 1 is the plan, and No. 2 the elevation of a skylight with curved bars, to find the hip: let A B be the seat of the centre bar, and D E the seat of the hip. Through any divisions 1 2 3 4 C of the rib, over A B draw lines at right angles to A B, and produce them to meet E D in *p o n m* D. From these points draw lines perpendicular to E D, and set up on them the corresponding heights from A B, as *l* 1 in *p* 1, *k* 2 in *o* 2, &c.

In the irregular octagonal skylight, *Fig.* 3, Nos. 1 and 2, the length and backing of the hips is formed as in *Fig.* 1, No. 1, by drawing A C perpendicular to A B, and setting up on it the height of the skylight in A C, then

drawing B C. The point F is found by drawing *g* F perpendicular to B C, from any part of B C, and through F drawing D E at right angles to A B to meet the adjacent sides of the skylight in D E, then making F *h* equal to F *g*, and joining D *h* E *h*.

In the octagonal skylight, *Fig.* 4, No. 1 and 2, which has curved ribs, the process of finding the hips is exactly similar to that employed in *Fig* 2, and need not be again described.

PLATE LXXXII., *Fig.* 1.—Nos. 1, 2 and 3 are the plan, side elevation, and end elevation of an irregular octagonal skylight, and *Fig.* 2, Nos. 1, 2, and 3, the plan, side elevation, and end elevation of an elliptical skylight, neither of which requires detailed description.

Fig. 3, No. 1, is the plan, No. 2 the end elevation, and No. 3 the side elevation, of an elliptical domical skylight. The section of the skylight on the minor axis is a circular segment, as seen in No. 2.

To find the ribs in *Fig.* 4, describe the quadrant A B, and in C B make the height, D B, equal to the height of the segment in No. 2; draw E D, and make E L equal to the length of the rib over the minor axis, and draw C L to find the bevil, L *w*, of the end. Divide the arc E L into any number of parts, and through them draw lines perpendicular to A C, and produce them indefinitely; draw also through, in the lower end of the rib, the line *m* K perpendicular to A C. Then from D as a centre, with the length of the longest semidiameter of the ellipse as radius, cut the line *m* K *n* K, and draw D K, and produce it to *n* to meet the perpendicular A *n* from A. Then the line D *n* will be the semi-axis major of an ellipse, as A C in *Fig.* 5, and the segment of it formed by the lines L *u m* K in *Fig.* 4 will be the rib standing over the semi-axis major. But all the ribs may be drawn by ordinates thus: From D, *Fig.* 4, as a centre, and with the lengths of the several ribs as radii, cut the line *m* K in H G F, and through these draw lines from D, meeting A *n*. Then the points where these lines are crossed by the perpendiculars to A C, passing through the divisions 1 2 3 4 L in the arc E L are the places of corresponding ordinates, by which the curves may be drawn, as D *u t* K in *Fig.* 5, D *u t* H in *Fig.* 6, D *u t* G *Fig.* 7, and D *u t* F in *Fig.* 8.

PLATE LXXXIII., *Fig.* 1.—No. 1 is the plan, and No. 2 the elevation, of an octagonal skylight. No. 3 is one of the sides laid over on the horizontal plane of projection. *Fig.* 2, No. 1, is the projection of a portion of the inside of the skylight looking up, and No. 2 is an elevation of a portion of the interior corresponding to the last. The mode of finding the lengths and backings of the hips and ribs is developed in the lower half of the plan. First, the hip B D. Make D E equal to the vertical height, and join B E. From any point *b* in B E let fall a perpendicular meeting B D in *c*; make *c a* equal to *c b*, and join C *a* and A *a*, and produce the latter to T. Then *c a* T is the bevil for the backing of the hip to be applied to the vertical side of the rib.

It will be seen that the rib K I is found in a similar manner from the right angled triangle K I L, of which the hypotenuse K L is the length of the rib as before.

In obtaining the ribs on the hither side of the octagon a compendious method is adopted. Let P Q be the seat of the hip, and N O, G F the seats of any other ribs; on F G construct the right angled triangle, F G H, as before, and from any point, R, in the hypotenuse draw R S, parallel to H G, and R *e* at right angles to F H. From R as a centre with any radius describe a circle as *d e f g*, and through *e* and *f* draw lines parallel to H G. At the points where these cut the seats of the ribs erect perpendiculars, as at *n m k l*, *p o i h*, and intersect them by tangents from the circle parallel to H G, as *d l m*, *g h o*; then join *m* S, and *o* S, and we obtain R S *o* and R S *m* as the bevils for the backing of the rib P Q, and in like manner the backing of any other rib is obtained.

Fig. 3, No. 1, shows the rib at F G in *Fig.* 1, No. 1, to a larger scale, and No. 2 shows a hip rib, the angle of backing, Q D S, being the same as A *a* C in *Fig.* 1, No. 1. No. 3' shows the common bar corresponding to the line I K in *Fig.* 1, No. 1, the angle P F *o*, being the same as W *r* X in the latter *Fig.* No. 4 is the hip as seen in *Fig.* 2, Nos. 1 and 2. The manner of finding the mouldings of the angle bars and ribs, as exemplified in this *Fig.*, has been already described in detail, and on examination it will be seen that the same letters refer to the same parts in all the mouldings, by which their correspondence can be readily traced.

Fig. 4 is the window bar.

PLATE LXXXIII^a.—*Pulpit with Acoustical Canopy.*—The drawings sufficiently explain the construction of the pulpit; and of the canopy, which is novel in design; we insert the following explanation, kindly supplied by its author, Mr. Wylson. The concave interior surface is generated from a point which appears in the flank elevation, a little above the level, and in advance, of the desk. In the first place, a parabola was drawn, planways and sectionally, having its focus in what was considered as the average position of the speaker's mouth; and a point was then found from which, as a centre, could be drawn, on plan and section, a circular arc coinciding as closely as possible with the parabolic curve, which point is the one already mentioned. The adopting a spherical surface in lieu of a paraboloidal one was for the purpose of simplifying the construction. The curves appear, in dotted lines, in the plan and flank elevation. The exterior, or back, of the canopy, bears no affinity to the interior it being straight horizontally. The canopy stands independently of the pulpit, and could be removed without interfering therewith.

HINGING.

PLATES LXXXIV.—LXXXVI.

The art of hanging two pieces of wood together, such as a door to its frame, a shutter to the lining, or a back flap to a shutter by certain ligaments that permit one or other of them to revolve. The ligament is termed a hinge.

Hinges are of many sorts, among which may be enumerated, butts, rising hinges, casement hinges, chest hinges, coach hinges, folding hinges, garnets, screw hinges, scuttle hinges, shutter hinges, desk hinges, back fold hinges, esses, and centre-pin or centre-point hinges.

As there are many varieties of hinges, there are also many modes of applying even the simplest of them, and much dexterity and delicacy is frequently required. In some cases the hinge is visible, in others it is necessary that it should be concealed. In some it is required not

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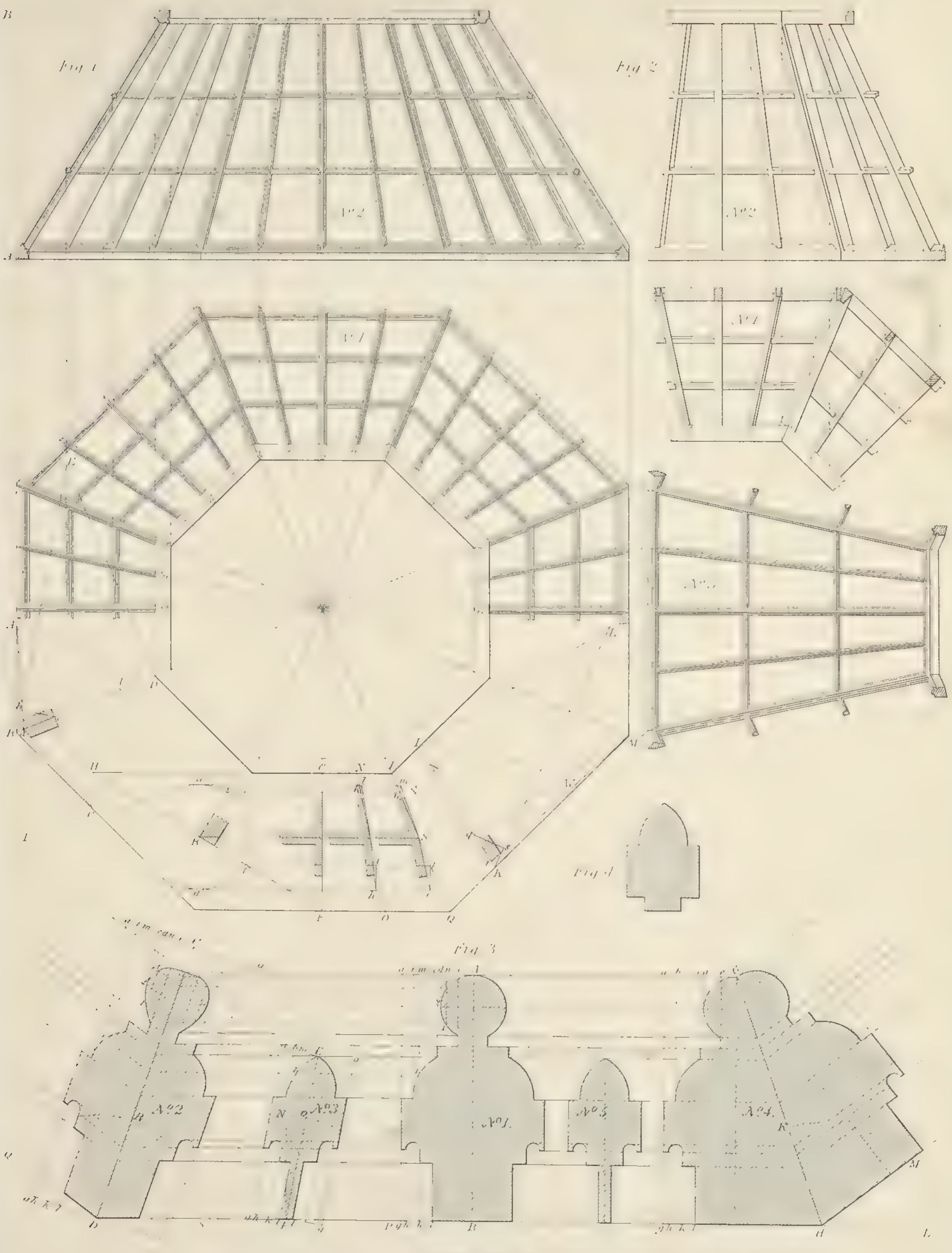
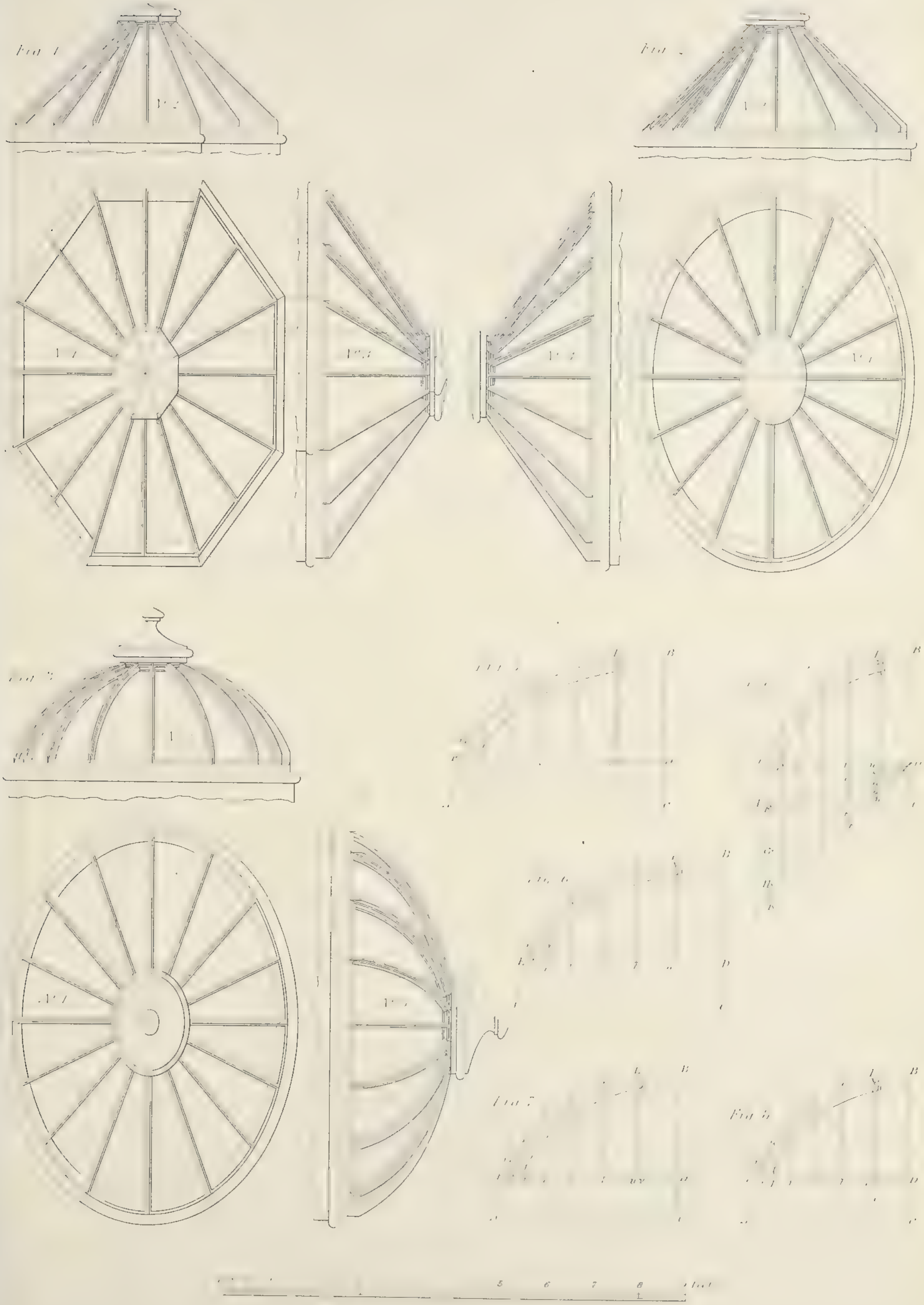
SKY LIGHTS.



P. Nicholson del. | H. A. Ferrari sc.

SKY LIGHTS



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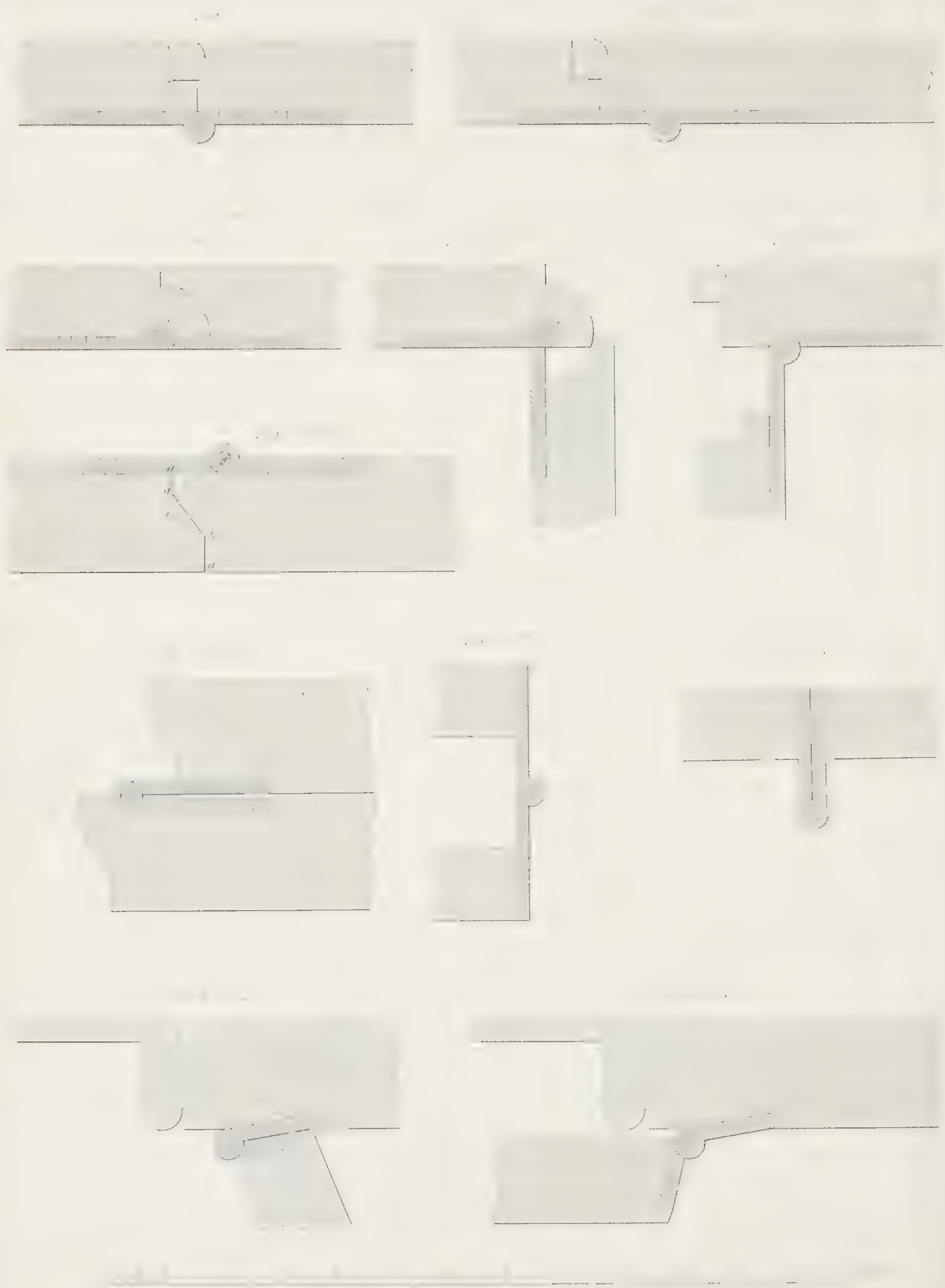
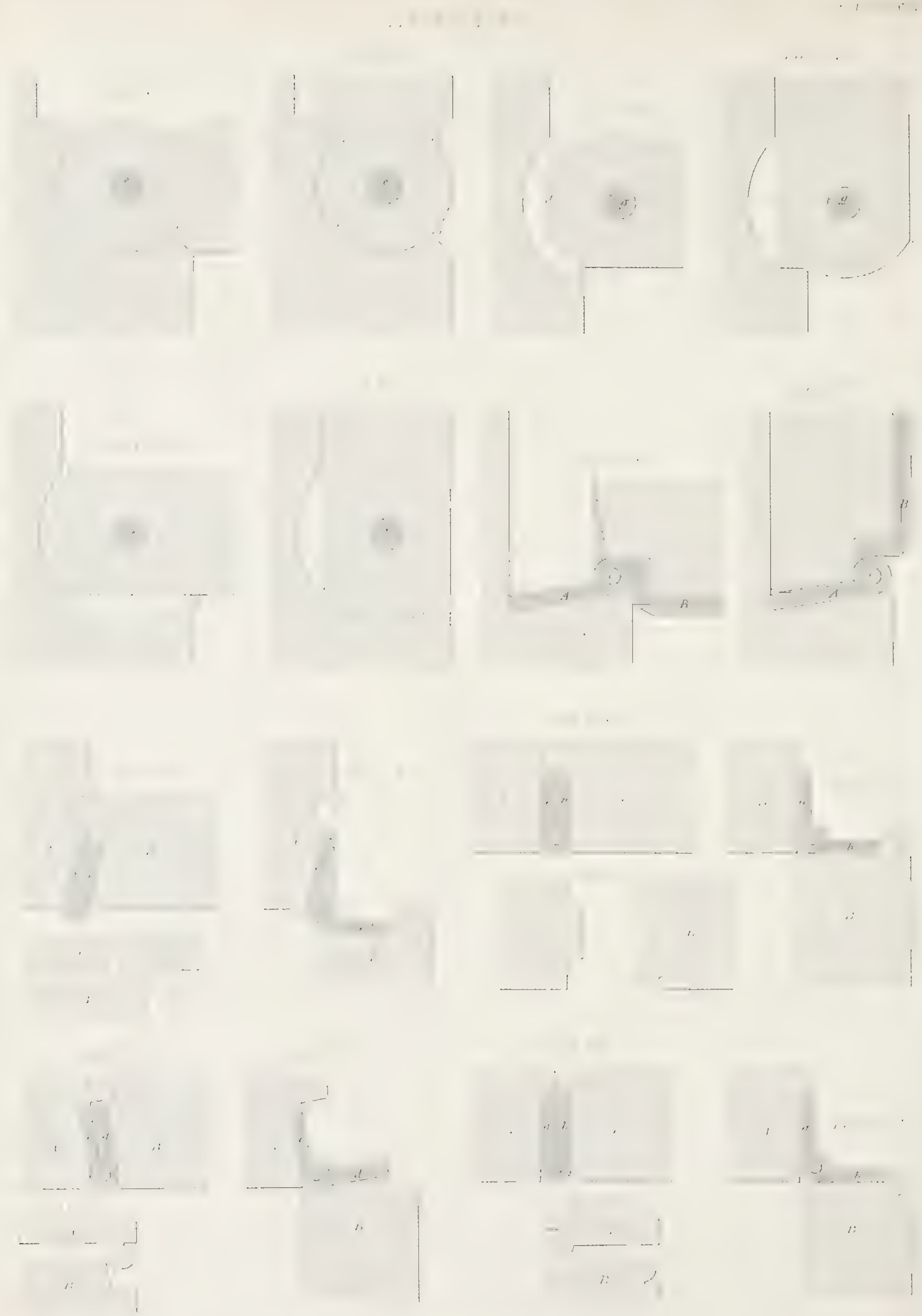
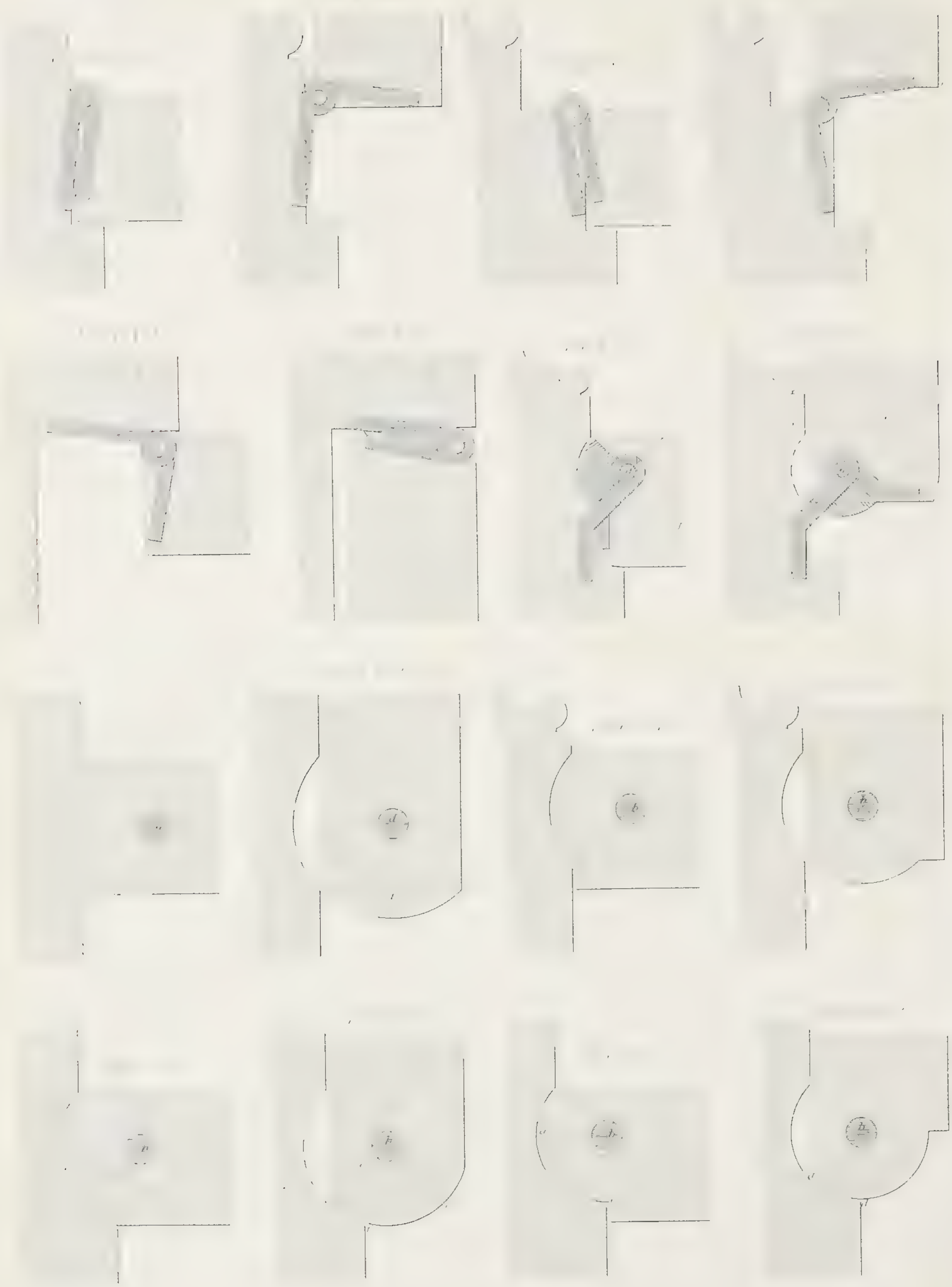






only that the one hinged part shall revolve on the other, but it shall be thrown back to a greater or lesser distance from the joint.

In Plates LXXXIV.—LXXXVI. are figured a great variety of modes of hinging.

Plate LXXXIV.—*Fig.* 1, No. 1, shows the hinging of a door to open to a right angle, as in No. 2.

Fig. 2, Nos. 1 and 2, and *Fig.* 3, Nos. 1 and 2. These figures show other modes of hinging doors to open to 90°.

Fig. 4, Nos. 1 and 2. These figures show a manner of hinging a door to open to 90°, and in which the hinge is concealed. The segments are described from the centre of the hinge g, and the dark shaded portion requires to be cut out to permit it to pass the leaf of the hinge $g\ f$.

Fig. 5, Nos. 1 and 2, show an example of centre-pin hinge permitting the door to open either way, and to fold back against the wall in either direction. Draw $a\ b$ at right angles to the door, and just clearing the line of the wall, or rather representing the plane in which the inner face of the door will lie when folded back against the wall; bisect it in f, and draw $f\ d$ the perpendicular to $a\ b$, which make equal to $a\ f$ or $f\ b$, and d is the place of the centre of the hinge.

Fig. 6, Nos. 1 and 2, another variety of centre-pin hinging opening to 90°. The distance of b from $a\ c$ is equal to half of $a\ c$. In this, as in the former case, there is a space between the door and the wall when the former is folded back. In the succeeding figures this is obviated.

Fig. 7, No. 1. Bisect the angle at a by the line $a\ b$; draw $d\ e$ and make $e\ g$ equal to once and a half times $a\ d$; draw $f\ g$ at right angle to $e\ d$, and bisect the angle $f\ g\ e$ by the line $c\ g$, meeting $a\ b$ in b, which is the centre of the hinge.

No. 2 shows the door folded back when the point e falls on the continuation of the line $f\ g$.

Fig. 8, Nos. 1 and 2. To find the centre draw $a\ b$, making an angle of 45° with the inner edge of the door, and draw $c\ b$ parallel to the jamb, meeting it in b, which is the centre of the hinge. The door revolves to the extent of the quadrant $d\ c$.

Plate LXXXV.—*Fig.* 1, Nos. 1 and 2; *Fig.* 2, Nos. 1 and 2; and *Fig.* 3, Nos. 1 and 2, examples of centre-pin joints, and *Fig.* 4, Nos. 1 and 2, do not require detailed description.

Fig. 5, Nos. 1, 2, and 3, show the flap with a bead a closing into a corresponding hollow, so that the joint cannot be seen through.

Fig. 6, Nos. 1, 2, and 3, show the hinge $a\ b$ equally let into the styles, and its knuckle forming a part of the bead on the edge of the style B. The beads on each side are equal and opposite to each other, and the joint pin is in the centre.

Fig. 7, Nos. 1, 2, and 3. In this example, the knuckle of the hinge forms portion of the bead on the style B, which is equal and opposite to the bead on the style A.

In *Fig.* 8, Nos. 1, 2, and 3, the beads are not opposite.

Plate LXXXVI.—*Fig.* 1, shows the hinging of a back flap when the centre of the hinge is in the middle of the joint.

Fig. 2, Nos. 1 and 2, shows the manner of hinging a back flap when it is necessary to throw the flap back from the joint.

Fig. 3, Nos. 1 and 2, is an example of a rule-joint, such as is required for the shutter in *Fig.* 2, No. 2, Plate LXXVI. The further the hinge is imbedded in the wood, the greater will be the cover of the joint when opened to a right angle.

Fig. 4, Nos. 1 and 2, shows the manner of finding the rebate when the hinge is placed on the contrary side.

Let f be the centre of the hinge, $a\ b$ the line of joint on the same side, $h\ c$ the line of joint on the opposite side, and $b\ c$ the total depth of the rebate. Bisect $b\ c$ in e and join $e\ f$; on $e\ f$ describe a semicircle cutting $a\ b$ in g, and through g and e draw $g\ h$ cutting $d\ c$ in h, and join $d\ h$, $h\ g$, and $g\ a$ to form the joint.

Fig. 5, Nos. 1 and 2, is a method of hinging employed when the flap on being opened has to be at a distance from the style. It is used in doors of pews to throw the opened flap or door clear of the mouldings of the coping.

Fig. 6, Nos. 1 and 2, is the ordinary mode of hinging the shutter to the sash frame.

LABOUR SAVING MACHINES.

In many of the operations of the joiner, in which numerous copies of the same thing have to be produced, accuracy is insured by introducing the principle of the guide, either to direct the tool over the work or the work over the tool. Examples of this are found in the mitre-box, the shoot blocks, and in the various kinds of fences and stops. These appliances are obviously the first step towards seeking the aid of machinery in performing operations requiring frequent repetition; and, accordingly, we find the principle of the guide applied first to simple sawing, then to planing, and subsequently to grooving, tonguing, mortising, tenoning, and shaping.

At first, as is usually the case, the applications of machinery to these works were in direct imitations of the actions of the workman. Thus, in the first planing machines the work was fixed, and the plane made to pass over it with a reciprocating motion; but, eventually the same effect came to be better produced by means entirely different. It was not till near the end of the last century that circular saws were introduced into England, although they were previously used on the Continent for small work in all kind of materials. The first attempt to construct a planing machine, is stated by Mr. Molesworth to have been made by a Mr. Hatton in 1776,* and the next attempt was made by Sir Samuel Bentham in 1791.

When Sir Samuel Bentham was in Russia, previous to the date mentioned, he had made considerable progress in contriving machinery for shaping wood, so as to insure accuracy and save manual labour. Besides the general operations of planing, rebating, mortising, dovetailing, grooving, bevelling, and sawing in curved, winding, and transverse directions, he had completed, in the way of example, an apparatus for preparing all the parts of a highly finished sash window; another for preparing every part of an ornamental carriage-wheel, and nothing remained for finishing the work of the joiner or wheelwright, but the putting the several component parts

* *On the Conversion of Wood by Machinery*, a paper read before the Institute of Civil Engineers, Nov. 17, 1857, by Guilford Lindsay Molesworth.

together. In 1793, Sir Samuel Bentham patented* several inventions, and as Mr. Molesworth well says, "had his ideas been carried out and the appliances of engineering been more perfect, he would doubtless have introduced many of those inventions which were years afterwards brought out and patented as new."

In 1802, Mr. Bramah patented machinery for producing straight, smooth, parallel, and curvilinear surfaces on wood. In his planing machine the cutting tools were fixed in apertures near the circumference of a horizontal wheel, moving with great velocity on a vertical axis, and the timber laid on a horizontal carriage was moved forward under their action. It was in principle somewhat the same as the machine figured in Plate LXXXVII. In 1807, Mr. Brunel's famous block machinery was set to work in Portsmouth dockyard. It is not necessary here to trace the progress of conversion of timber by machinery; suffice it to say that Thomson's machinery for sawing, gauging, and grooving and tonguing flooring-boards was in operation in 1826, and in 1827, Mr. Muir, of Glasgow, patented a machine for working flooring-boards, which has since served as a model for those subsequently introduced in Britain. In this machine the bottom of the board was roughly planed by a rotatory adze, while another similar adze operated on the upper surface. The board then passed between two fixed cutters set obliquely, which removed a shaving of the length and width of the deal, while two revolving cutters or saws made the sides parallel, and two other cutters grooved or tongued the edges. In the hands of Mr. M'Dowall, of Johnstone, the flooring machine has in design and workmanship approached perfection.

But it is not to these machines which we here desire to direct the attention of the reader. Machinery so extensive and capable of producing so much, will not supply the requirements of the ordinary workshop. It is expensive in its first cost, and requires a great amount of the same kind of work to keep it in remunerative operation. For the ordinary workshop, where the trade is limited and much varied, the simpler though less perfect machines, which are used in America in aid of the workman, are more suitable; and it is to the description and illustration of one or two of the more generally useful of these machines that we propose to devote these pages and plates.

Plate LXXXVII.—*Figs.* 1, 2, 3. The small saw bench which is here figured, is suitable for jobbing work. It occupies little space, and can be applied in plain and bevel sawing, mitring, tenoning, rebating, &c. The bench is supported on four stout legs, firmly united by means of the top rails, and the middle rails which carry the plummer blocks of the driving pulley. It is only 3 feet 2 inches long, 2 feet 2 inches wide, and 3 feet $6\frac{1}{2}$ inches high. Its dimensions are confined within these narrow limits, by the mode adopted of banding the pulleys, about to be described, and which is the subject of a patent.

Fig. 1 is a plan of the top; *Fig.* 2 is an elevation of one end; and *Fig.* 3 is an elevation of the front of the bench. The same letters refer to the same parts in all the figures. *a a a a* are the supports, *b b* rails on which the plummer blocks of the driving pulley are fixed, and which carry also the braced upright *c c*, to which the cast-iron bracket, supporting the axis of the saw *d d*, is attached; *e e* is the driving pulley, moved by a handle attached to its axis; *f f* are radial iron bars moving freely on the axis of the driving pulley, and carrying at their outer end the tension pulley *g g*. The diameter of the driving pulley is $23\frac{1}{2}$ inches, the diameter of the tension pulley is $7\frac{3}{4}$ inches, the axle of the saw is $1\frac{1}{4}$ inch diameter; it is suspended on conical steel centres, and serves as a third pulley. The band passes over the tension pulley and over the saw axle, and its lower web is pressed against the periphery of the driving pulley by the weight of the tension pulley. The saw is 8 inches in diameter, and makes $15\frac{1}{2}$ revolutions for each turn of the handle.

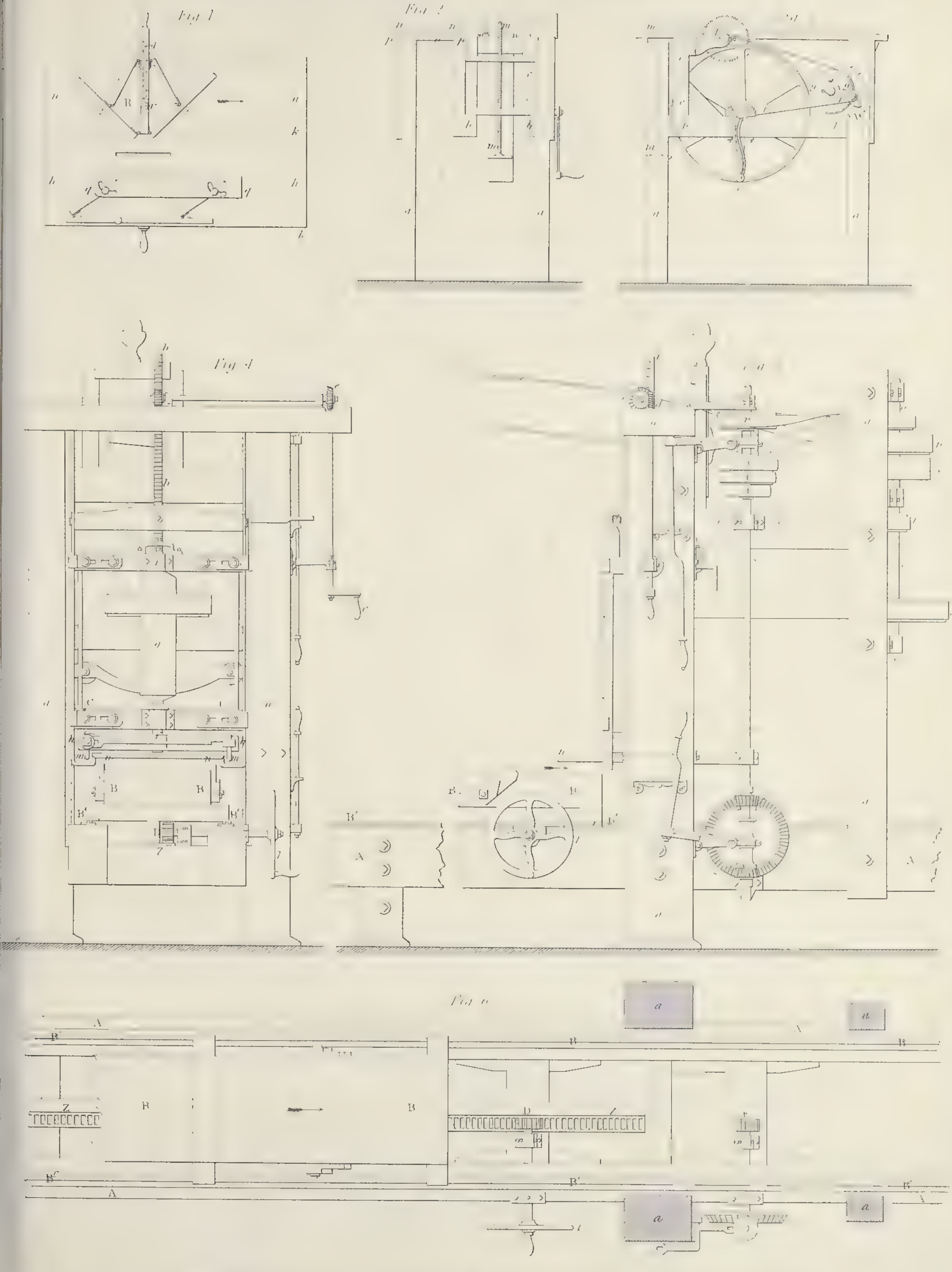
Fig. 1 is the plan of the top of the machine. It is composed of a front board *h h*, hinged to the frame at *k*, so that its other end can be elevated by means of a wooden screw *m*, as seen by the dotted lines in *Fig.* 3. Through a slot in the top of this the saw *d d* works; *n n* is the back board, which is capable of being slidden along parallel to the blade of the saw, being guided by a fillet on its under side, sliding in a groove in the fixed top-board of the machine below it, seen at *o o*, *Fig.* 2. This sliding board has various holes, some screwed and others plain, for fixing the fences, guides, and stops to be hereafter mentioned; and as the pins and screws which secure these project below the bottom of the board, there are longitudinal channels grooved out in the path of these holes in the fixed top *p p*, underneath.

When the machine is used for ripping or cross-cutting, a parallel motion fence *q q* is screwed by a wooden hand-screw to the front board *h h*, *Fig.* 1. The distance between the fence and blade of the saw regulates the scantling to be cut off; a stop is fixed to one of the holes in the sliding board, against which the stuff is held, and the board being slidden along in the direction of the arrow, the stuff is acted on by the saw. By raising the front board by means of the screw *m*, the machine can be adjusted for tenoning. The board is raised until just so much of the saw is exposed as is equal to the depth of the shoulder of the tenon, and the fence is set to the proper length of the tenon. The stuff is passed along, and the shoulder on one side is cut; it is then reversed and the operation repeated for the other side. When the shoulders of all the pieces have been cut, the front board is dropped until the saw projects through to the length of the tenon; the fence is then moved towards the saw, till the space between them is just equal to the depth of the shoulder, and the stuff is then passed through, on end, twice; and if the adjustment has been correctly made the tenon is formed perfectly square and clean. For bevel cutting and mortising, the guide shown at R, *Fig.* 1, is used. It consists of a stock, which, by means of the handscrew *r*, can be fixed to the sliding top. To the end of the stock are hinged the arms 2 2, and to a block sliding freely in a slot in the stock are hinged the short arms 3 3, hinged also at their other end to 2 2. By means of the screw 4 the block is made to traverse the slot, and the arms 2 2 are moved so as to make a greater or less angle with the stock.

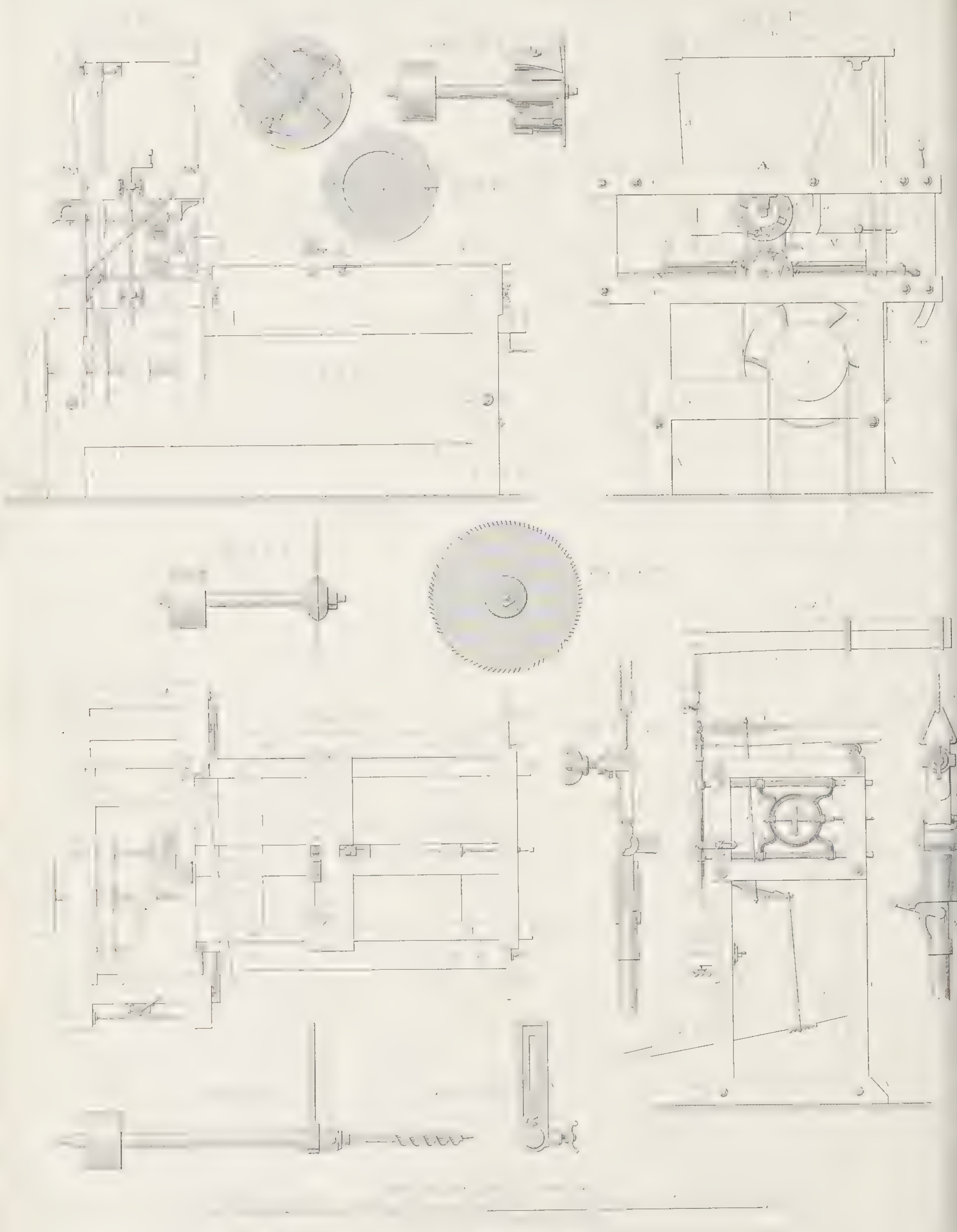
* In referring to the specification of this patent of 23d April, 1793, the editor of the *Mechanic's Magazine*, a competent authority, says it is a perfect treatise on the subject, indeed the only one worth quoting from which has to this day been written on the subject. Dec. 16, 1848.

LABOUR SAVING MACHINES.

AMERICAN CIRCULAR SAW BENCH. FURNESS'S PLANING MACHINE.



FURNESS'S PATENT MORTISING AND TENONING MACHINES.



When mitring is to be performed, the arms 2 2 are adjusted, to make an angle of 45° with the plane of the saw, and the stuff being held against one or other of them, the top board is shot so as to bring it under the operation of the saw.

On the inner end of the shaft of the driving pulley, there is a crank which may be acted on by a treadle like a turning lathe when the stuff is thin; but, in ordinary cases, the machine requires two operators. It is not necessary to describe further the many operations which this little handy bench may aid in performing with accuracy and despatch.

Figs. 4, 5, 6, illustrate Furness' patent planing machine. In this machine the stuff is operated upon by cutters, held by horizontal arms fixed to a vertical shaft, and it is in this respect similar to the machine patented by Mr. Bramah in 1802, but it is much simpler and less expensive. The same letters refer to the same parts in all the figures. A A *a a* is the fixed framing of the machine. B B a travelling bed piece, on which the stuff to be operated on is fixed. Its upper surface, on which the stuff rests, is itself planed true by the revolving cutters. It travels on cast-iron ways B′ B′, and has a rack Z Z fixed to its under side, into which a pinion D on the hand-wheel 1, and also a pinion E on the bevel-wheel 2, gear. The cutter frame C C is of cast-iron; it slides between the vertical pieces of the main framing *a a*, and can be raised and lowered by means of the toothed rack *b*, which is acted upon by the winch handle *c*, by means of the screw and bevel pinion *d* and *e*. This frame carries a vertical spindle *f*, with a long pulley of timber *g*, fitted to it. The lower end of the spindle has attached to it the arms *h h*, which carry the cutters *m m*. On the lower part of the frame C is fixed the cast-iron disk plate *n n*, which presses on the timber while the cutters operate upon it close to its periphery. The main driving belt gives motion to the shaft *o o*, by means of the fast pulley *p*, and is shifted to the loose pulley *p′*, when the machine is to be stopped. The pulley *q* on the shaft *o* drives the long pulley *g* on the cutter shaft, and another pulley on the top of *o* drives the pulley *r* on the shaft *s*. A third pulley *t*, fixed on the shaft *o*, gives motion to a pulley *v*, carried by an intermediate shaft, shown by dotted lines, and through this intermediate shaft and its pulleys, to the pulleys *w w′ w″*, moving also on the shaft *s*. *x x* is a clutch, by means of which either the pulley *r* or the pulleys *w* can be keyed to the shaft, and while the other remains loose, and thus it may be made to revolve in either direction. The shaft *s* has two sliding bevel pinions *y y*, at its lower end, either of which can be thrown into gear with the bevel wheel 2, which, as has been said, has a pulley on its shaft gearing into the rack Z on the under side of the travelling bed B B. When by means of the upper handle and clutch *x x*, the pulley *r* is made to revolve with the shaft, the travelling bed brings the stuff forward in the direction of the arrows, under the operation of the cutters. When the timber has all been passed through, *r* is thrown loose, and *w* is fixed, and the carriage moves back with rapidity. The carriage can also be moved backwards or forwards, by throwing the pinions *y y* out of or into gear, and it can also be moved by hand through the wheel *s*.

PLATE LXXXVII.[a]—*Fig.* 1, Nos. 1 to 10 are plans, elevations, and details of Furness' patent tenoning machine.

Fig. 1, No. 1 is the plan, *Fig.* 1, No. 2, a side elevation, and No. 3 an end elevation. The same letters refer to the same parts in all these. This machine, by means of revolving cutters *a a*, forms both sides of the tenon simultaneously. The stuff to be operated upon is laid on a travelling bed M M, which moves transversely across the machine, so as to pass the stuff between the cutters. The lower cutter *b* is supported by the main frame B B, and the upper cutter *a* by the moveable frame C C, which can be raised or lowered, so that it can be adjusted to the thickness of stuff or depth of shoulder required; and the bed M M can also be raised or lowered, so as to complete the adjustment. The moveable stop *p q* regulates the length of the tenon. The main driving pulley *f* has another pulley *z*, keyed on the same shaft, a belt from which passes over pulley *h* of the upper cutter, and then under the pulley *k* of the lower cutter, and over a tension pulley L, and then returns. By this arrangement the cutters move in opposite directions; and to allow of the adjustment for the various thicknesses of wood, and keep the belt tight on the pulleys, a simple contrivance is used. A leather belt *s s* is attached to the bottom of the stirrup spar *l l*, which is attached to the hinged cross-head K, carrying the tension pulley L, and the belt then passes through under an eccentric paul at 2 2, which holds it tight at any point required. We shall now describe the parts of the machine in detail. A A upright supports, which with the rails B B form the main framing of the machine, carrying the driving pulley and the lower cutter *b*; C C upright framing, which moves round *c* as a centre, and its opposite end can be lowered or raised by adjusting the radial slot at E, and for finer adjustment by the vertical screw F. It is further supported by the wrought-iron stay-rod *g*. This frame carries the upper cutter *a*, and, by means of the uprights H H, and jointed cross piece K, the tension pulley L. M M the bed frame on which the stuff to be operated on is laid. It is supported on the slotted upright board *m m*, the under edge of which rests on the wedge pieces *n n*. By means of a screw, the handle of which is seen at *o*, the wedges have a backward and forward motion, and raise and lower the frame as occasion may require; and it is fixed when adjusted by the screw *m m*, working through the slots in the upright supports. The moveable fence *p q* consists of two parts, the distance between which can be regulated, and indicates the length of the tenon. The stuff is placed between the fence *q* and the cutter, and the fence *p* is set to the proper length of the tenon; the stuff is then advanced so as to rest against *p*, and the other end consequently projects through the cutters to the required distance. The fences are kept in their position by springs, which can be depressed by the pressure of the wood. The wood is also pressed against the stops *r r*, and is kept fast on the frame by the lever *s s*, the outer end of which is grasped in the left hand of the workman, together with a little iron handle *t*, fixed to the frame, which he thus uses like pincers, and the bed frame is at the same time pushed from him by his right hand, so as to bring the stuff under the action of the cutters. The operation, which takes long to describe, is performed very rapidly.

Fig. 1, No. 4 is the side view of one of the cutters.

No. 5 is the inside view of the disk of the same, and No. 6 the front or outside of the disk, all drawn to a larger scale.

We have described the machine as adapted for tenoning, but it can be used also for sawing and boring. Nos. 7 and 8 are a profile and front view of the saw, which when used takes the place of the lower cutter, and is driven by reversing the banding, so as to cause the saw to revolve in a direction opposite to the motion of the sliding frame.

The boring tool is seen in profile in No. 9. It is suspended between the piece u, fixed to the outside of the frame c c, *Fig.* 1, No. 3, and the slotted piece V, No. 10, which is attached to the inner side of the frame by a clamp screw working through the slot. It is driven by a belt from the small pulley W, *Fig.* 1, No. 2, passing over the pulley x, carried by its own spindle.

Fig. 2, Nos. 1 and 2 show Furness' patent mortising machine.

Fig. 2 is a side elevation, and *Fig.* 2, Nos. 1 and 2, details of the chisel socket.

The machine consists of a sill A, bolted to the floor or otherwise steadied, two uprights B B, and two cross rails c c. D is a lever moving on a centre at d, and having the mortising tool attached to its other end at e, a treadle E, acting on the lever D, by the two iron straps f f, and the interposed ratchet lever F. The chisel socket, besides being attached to the lever D, is suspended to a spring pole G fixed to the ceiling of the apartment, whose elasticity raises it after every cut. The chisel socket H slides in the two eyes h h, formed on the ends of the bars of the iron frame k k. These bars slide through the uprights B B, and by means of the screw L can be moved forwards or backwards, so as to move the cutting chisel further from or nearer to the frame, according to the thickness of stuff. l is the bench or rest on which the stuff is laid. It is carried by the piece m, which has a bolt passing through a slot in the upright, so that by means of the clamping screw n it can be raised or lowered. To prevent the stuff rising with the chisel, there is a stop s s on each side. These work through eyes in the slotted pieces r r, and by means of screws can be adjusted along with the chisel. The depth of the cut of the chisel is regulated by moving the straps f f to various notches in the levers D F and E.

The *Figs.* 2, Nos. 1 and 2, show in detail the manner of suspending the chisel socket. 1 is a rope attached to the spring pole G, 2 is a triangular iron link, to the top of which is attached the rope, and to the bottom a leather belt 4, clamped by the screw apparatus at 3, so that it can be lengthened or shortened at will. 5 is the end of the lever D, showing the manner in which it is attached to the socket; 8 is the socket turning freely round its axis in a head 6. This head has two wings 6 6 diametrically opposite, with square notches in them, into which the detent 7 falls. When half the length of the mortise has been cut, the detent is withdrawn from the notch it may happen to be in, and the chisel is turned round till the detent falls into the opposite notch, and the remaining half of the mortise is completed, working from its extremity again towards the centre.

Fig. 509

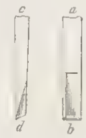


Fig. 509, c d is a side, and b a a front view of the chisel used in mortising.

This machine is also used for making dowels or wooden pins, by substituting a cylindrical cutter for the chisel.

In conclusion, we note a few practical points to be observed in the construction of these machines.

In machines with revolving cutters the general opinion is, that the greater the speed of the cutting-tool the better will be the quality of the work. The practical limit, however, appears to be between 2500 and 3500 revolutions per minute. A higher velocity heats the bearings, destroys the balance, and causes injurious vibrations. To produce a good result the travel of the work should be very slow relatively to the travel of the cutters. In some of the planing machines the cutters revolve with a velocity of 7000 feet per minute, while the work advances at the rate of only 30 feet, but as a general rule the work travels about $\frac{1}{20}$ of an inch for each stroke of the cutters. In order to withstand this high velocity, the framing of the machine requires to be perfectly constructed. It should be of hard wood; and Mr. Molesworth directs—"that the joints be not made so as to depend simply on mortise and tenon; they should be shouldered in." "The bearings are sometimes made of an alloy, composed of 100 parts tin, 10 parts antimony, and 2 parts copper. In forming them the spindle is accurately fitted in its place, and the alloy is cast round it into an iron shell, which forms the plummer block. The parting of the base and cap is made by inserting a thin sheet of iron in the proper position." "Another peculiarity is the method of securing steadiness in high-speeded shafts; this consists in cutting in the journal a succession of angular threads, with angular grooves between. The alloy is cast round the journal as before, and great steadiness of action is secured; whilst the oil remains in the bearings without difficulty. An adjusting axle box is also much used; it is centred on two set screws, so as to allow it to turn slightly in the event of the opposite bearing being unevenly worn, and thus the extra wear and chatter which would ensue at high speeds are obviated."

PART SEVENTH.

STAIRS AND HAND-RAILING.*

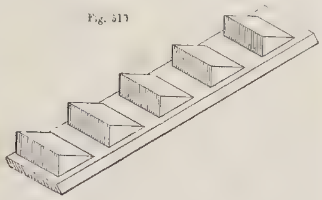
Stairs are constructions composed of horizontal planes elevated above each other, forming steps; affording the means of communication between the different stories of a building.

In the distribution of a house of several stories, the stairs occupy an important place. In new constructions their form may be regular, but in the reparation or remodelling of old buildings, the first consideration is generally to make the distribution suitable for the living and lodging rooms, and then to convert to the use of the stairs the spaces which may remain; giving to them such forms in plan as will render them agreeable to the sight, and commodious in the use.

A great variety of form in the plans of stairs is thus in a measure forced on the designer, leading to many ingenious contrivances for overcoming difficulties, disguising defects, and enhancing accidental beauties, which he might not have adopted if unfettered in his choice. These inventions, originated by necessity, are again applied in cases where the necessity may not exist, recommended by their intrinsic beauty, or by the desire for variety in design.

As introductory to the construction of stairs, a selection of some of the more simple contrivances are here presented.

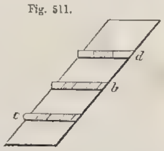
Fig. 510.



That kind of stair which, after the common ladder, is the most simple, is formed of a thick plank placed at a convenient angle to form the ascent, and upon it are nailed pieces of wood to give a firm footing. This (Fig. 510) is often used in scaffolding.

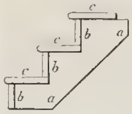
The stair next in degree is composed of horizontal planks forming steps, just sufficiently wide to give a footing; the planks are tenoned on the ends and let into mortises in two raking planks; the mortises are sometimes rectangular, as at *d* (Fig. 511), and sometimes they follow the inclination of the sides, as *b* and *c*. In the better sort the outer edge of the step has a nosing, as at *c*. The tenons of the steps are sometimes made so long as to pass entirely through the sides, and are secured by keys on the outside:—to preserve the planks which form the steps from splitting, the sides of the raking pieces are grooved to receive their ends. The opposite side pieces, too, are often bound together by iron rods; one end of each rod having a rivet head, and the other end being screwed with a nut to embrace the side pieces. Such rods should be placed near the middle of a step, and close to its under side.

Fig. 511.



Another method of forming a stair expeditiously, is to notch out the side pieces on their upper edge sufficiently to receive the steps and risers, thus; *a a* the side pieces, *b b* the risers, and *c c* the step boards or treads (Fig. 512). The risers are nailed at the ends to the sides or strings, and the steps are nailed to the risers and also to the strings. Such methods as have been described are often used in warehouses, factories, and agricultural buildings.

Fig. 512.



There is a contrivance for economizing space sometimes used, which, perhaps, it may be well to mention, as the ascent is thereby made in about one half the space otherwise required.

The width of this kind of stair is divided into two sets of steps, both of equal length and width, but the risers, except the first and last, are made twice the usual height; thus, if the line *a* B (Fig. 513) be 72 inches, and the width C D 33, and it is necessary to rise 80 in., divide the line *a* B in nine equal parts, and make the step equal to two of these parts; also, divide the width in two equal parts, and the height into ten equal parts, which gives 8 inches for the tread, 8 inches for the bottom riser, and 16 inches for the intermediate risers *a a*, &c., and 8 for the top riser *b*. Arrange the risers in such order that the face line of one riser shall be in the midway betwixt the face of the one next below and the one next above, as will better be seen by reference to Fig. 514. The height of the risers is so disposed that the bottom riser shall have the face of the first step 8 inches from

Fig. 513.

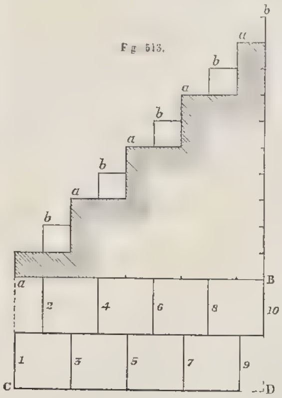


Fig. 514.

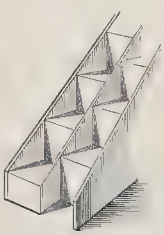
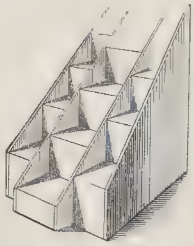


Fig. 515.



* Contributed by Mr. Mayer, Montpelier Villas, Cheltenham.

the floor, whilst the first step on *b* shall be 16 inches from the floor, and the succeeding risers 16 inches each.

In using this stair, one foot is placed on a step of one flight, as at *a* (Fig. 513), and the other on a step of the other flight, as at *b*, and so on alternately. Such stairs will only admit the passage of one person at a time.

When it is required to admit of two persons passing each other, three flights are necessary, the centre flight being made wider than the exterior flights (Figs. 515 and 516). This contrivance may be used in places not sufficiently spacious to admit of stairs of the usual construction.

Fig. 516.

When houses began to be built in stories, the stairs were placed from story to story in straight flights like ladders. They were erected on the exterior of the building, and to shelter them when so placed, great projection was given to the roofs. To save the extent of space required by straight flights, the stairs were made to turn upon themselves in a spiral form, and were inclosed in turrets. A newel, either square or round, reaching from the ground to the roof, served to support the inner ends of the steps, and the outer ends were let into the walls, or supported on notched boards attached to the walls.

At a later period the stairs came to be inclosed within the building itself, and for a long time preserved the spiral form, which the former situation had necessitated.

DEFINITIONS.—The apartment in which the stair is placed, is called the *staircase*.

The horizontal part of a step is called the *tread*, the vertical part the *riser*, the breadth or distance from riser to riser the *going*, the distance from the first to the last riser in a flight the *going of the flight*.

When the risers are parallel with each other, the stairs are of course *straight*.

When the steps are narrower at one end than the other, they are termed *winders*.

When the bottom step has a circular end, it is called a *round-ended step;* when the end is formed into a spiral, it is called a *curtail step*.

The wide step introduced as a resting-place in the ascent is *a landing*, and the top of a stair is also so called.

When the landing at a resting place is square, it is designated a *quarter space*.

When the landing occupies the whole width of the staircase it is called a *half space*.

So much of a stair as is included between two landings is called a *flight*, especially if the risers are parallel with each other: the steps in this case are *fliers*.

The outward edge of a step is named the *nosing;* if it project beyond the riser, so as to receive a hollow moulding glued under it, it is a *moulded nosing*.

A straight-edge laid on the nosings represents the angle of the stairs, and is denominated the *line of nosings*.

The raking pieces which support the ends of the steps are called *strings*. The inner one, placed against the wall, is the *wall string;* the other the *outer string*. If the outer string be cut to mitre with the end of the riser, it is a *cut and mitred string;* but when the strings are grooved to receive the ends of the treads and risers, they are said to be *housed*, and the grooves are termed *housings*.

Stairs in which the outer string of the upper flight stands perpendicularly over that of the lower flight are called *dog legged stairs*, otherwise *newel stairs*, from the fact of a piece of stuff called a *newel*, being used as the axis of the spiral of the stair; the newel is generally ornamented by turning, or in some other way. The outer strings in such stairs are tenoned into the newel, as also are the first and last risers of the flight.

When the upper and lower strings are separated by an interval, the space is called the *well-hole*. If the front string is mitred or bracketed, it is called an *open string;* if grooved, a *close string*. Where there is a well-hole and no newel, and the string is continued in a curve, the curved part of the string is said to be *wreathed*, and the stair is then a *geometrical stair*.

Besides the support afforded by the strings the stair is sustained by pieces placed below the fliers; these are called *carriages;* they are composed of longitudinal and transverse pieces; the former are called *rough strings*, the latter *pitching pieces;* and the rough strings have triangular pieces called *rough brackets*, fitted to the underside of the tread and riser.

The winders are supported by rough pieces called *bearers*, wedged into the wall, and secured to the strings.

When the front string is ornamented with brackets, it is called a *bracketed stair*.

Where communication between the stories is frequent, the qualities necessary in the stairs are ease and convenience in using, combined with sufficient strength and durability. Economy of space in the construction of stairs is an important consideration. To obtain this, the stairs are made to turn upon themselves, one flight being carried above another at such a height as will admit of head room to a full-grown person.

Method of setting out stairs where the building is already erected, or the general plan of the building is understood.

The first objects to be ascertained are the situation of the first and last risers, and the height of the story wherein the stair is to be placed. A sketch is made of the plan of the hall to the extent of 10 or 12 feet from the supposed place of the foot of the stair, and all the doorways, branching passages, or windows which can possibly come in contact with the stair from its commencement to its expected termination or landing are noted This sketch necessarily includes a portion of the entrance-hall in one part, and of the lobby or landing in the other, and on it have to be laid down the expected lines of the first and last risers. The height of the story is next to be exactly determined and taken on a rod; then, assuming a height of riser suitable to the place, a trial is made, by division, how often this height is contained in the height of the story, and the quotient, if there be no remainder, will be the number of risers in the story. Should there be a remainder on the first division, the operation is reversed, the number of inches in the height being made the dividend, and the before-found quotient the divisor, and the operation of division by reduction is carried on, till the height of the riser is obtained to the thirty-second part of an inch. These heights are then set off on the story rod as exactly as possible. The next operation is to show the risers on the plan, but for this no arbitrary rule can be given; the designer must exercise his ingenuity.

When two flights are necessary for the story, it is desirable that each flight should consist of an equal number of risers; but this will depend on the form of the staircase, the situation and height of the doors, and other obstacles to be passed over or under, as the case may be. Try what the width of the tread will be by setting off, upon the line $n\ a$ in Fig. 519, the width of the landing from the wall A B; and dividing the length of the flight into as many equal spaces as it is intended there should be steps in each flight. The landing covers one riser, and therefore the number of steps in a flight will be always one fewer than the number of risers. The width of tread which can be obtained for each flight will thus be found, and consistent with the situation, the plan will be so far decided. A pitch-board should now be formed to the angle of inclination: this is done by making a piece of thin board in the shape of a right-angled triangle, the base of which is the exact going of the step, and its perpendicular the height of the riser.

If the stair be a newel stair, its width will be found by setting out the plan and section of the newel on the landing; (if one newel, it should, of course, stand in the middle of the width;) then, in connection with the newel, mark the place of the outer or front string, and also the place of the back or wall string, according to the intended thickness of each. This should be done not only to a scale on the plan, but likewise to the full size on the rod. Set off on the rod, in the thickness of each string, the depth of the grooving of the steps into the string; mark also on the plan the place and section of the bottom newel; the same figure answers for the place of the top newel of the second flight, the flights being supposed of equal length. The front string is usually framed into the middle of the newel, and thus the centres of the rail, the newels, the balusters, and the front string range with each other; the width of the flights will thus be shown on the rod.

It is a general maxim that the greater the breadth of a step the less should be the height of the riser; and conversely, the less the breadth of step, the greater should be the height of the riser. Experience shows that a step of 12 inches width and $5\frac{1}{2}$ inches rise, may be taken as a standard; and if from this it is attempted to deduce a rule of proportion, substituting, for the sake of whole numbers, the dimensions in half-inches, namely 24 and 11, then, in order to find any other width corresponding in inverse proportion,

Say as 24 : 11 :: 12 : 22
24 : 11 :: 19 : 13·8
24 : 11 :: 20 : 13·2

Thus, it will be seen that a step of 6 inches in width will require the riser to be 11 inches, a step of $9\frac{1}{2}$ inches will need the riser to be nearly 7 inches, and that a step of 10 inches requires a riser of about $6\frac{5}{8}$ inches.

The same thing is thus otherwise expressed. Let T be the tread, and R the riser of any step which is found to have proper proportion, then to find the proportion of any other tread t, and riser r, $\frac{R \times T}{r} = t$, or $\frac{T \times R}{t} = r$.

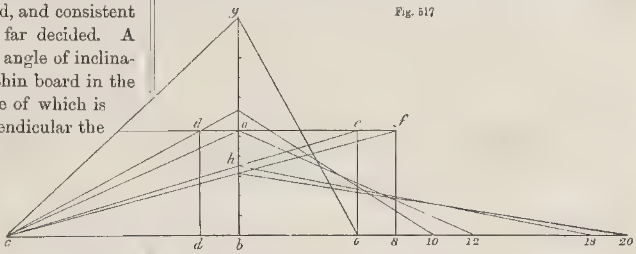
Take, for example, a step with a tread of 12 and a riser of $5\frac{1}{2}$ inches as the standard, then to find the breadth of the tread when the given riser is 8 inches, and substituting these values for t and r in the formula, we have $\frac{12 \times 5\frac{1}{2}}{8} = 8\frac{1}{4}$ inches as the breadth of tread.

Suppose, again, the given breadth to be 13 inches, we have $\frac{12 \times 5\frac{1}{2}}{13} = 5\frac{1}{13}$ inches as the height of riser.

This process of inverse proportion may be performed graphically as follows:—

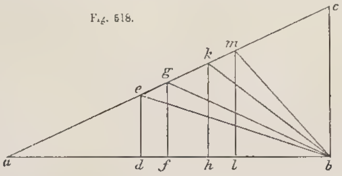
Let the tread and riser of a step of approved proportion be represented by the sides $c\ b$, $b\ a$, of the triangle $a\ b\ c$, Fig. 517. Through the point a, draw a line $d\ a\ f$, parallel to the step line $c\ b$. Then, to find the riser for any other step, set off on the line $c\ b$, from the point c to d, the required width of a step, say 10 inches, and draw $d\ d$; draw also $c\ d$, and continue it to the line $b\ a$, and the point of intersection there will show the height of riser corresponding to the tread $c\ d$. In like manner, if the width given be 18 inches, set it off in the point 6; draw 6 e and $c\ e$, and the intersection at h will be obtained, giving $3\frac{3}{8}$ inches for the height of the riser. A width of 20 inches will show a height of 3·3 inches. On the right side of the figure is shown each step we have mentioned, connected with its proper riser, thus exhibiting the angle of pitch.

Fig. 517



The same end nearly is arrived at thus:—In the right-angled triangle $a\ b\ c$, Fig. 518, make $a\ b$ equal to 24 inches, and $b\ c$ equal to 11 inches, according to the previous standard proportion; then to find the riser corresponding to a given tread, from b set off on $a\ b$ the length of the tread, as $b\ d$, and through d draw the perpendicular $d\ e$, meeting the hypothenuse in e; then $d\ e$ is the height of the riser, and if we join $b\ e$, the angle $d\ b\ e$ is the slope of the ascent. In like manner, where $b\ f$ is the width of the tread, $f\ g$ is the riser, and $b\ g$ the slope of the stair. A width of tread, $b\ h$, gives a riser of the height of $h\ k$, and a width of tread equal to $b\ l$, gives a riser equal to $l\ m$.

Fig. 518.



It is conceived, however, that a better proportion for steps and risers may be obtained by the annexed method:—

Set down two sets of numbers, each in arithmetical progression; the first set showing the width of the steps, ascending by inches, the other showing the height of the riser, descending by half inches. It will readily be seen that each of these steps and risers are such as may suitably pair together.

Treads. inches.	Risers. inches.
5	9
6	$8\frac{1}{2}$
7	8
8	$7\frac{1}{2}$
9	7
10	$6\frac{1}{2}$
11	6
12	$5\frac{1}{2}$
13	5
14	$4\frac{1}{2}$
15	4
16	$3\frac{1}{2}$
17	3
18	$2\frac{1}{2}$

It is seldom, however, that the proportion of the step and riser is exactly a matter of choice—the room allotted to the stairs usually determines this proportion; but the above will be found a useful standard, to which it is desirable to approximate.

In better class buildings the number of steps is considered in the plan, which it is the business of the architect to arrange, and in such cases the height of the story rod is simply divided into the number required.

Plans of Stairs.—Before giving examples of the various forms of stairs ordinarily occurring in practice, we shall with some minuteness illustrate the mode of laying down the plan of a stair, where the height of the story, the number of the steps, and the space which they are to occupy are all given.

The first example shall be of the simplest kind, or dog-legged stairs.

Let the height (Fig. 519) be 10 feet, the number of risers 17, the height of each riser consequently $7\frac{1}{17}$, and the breadth of tread $9\frac{1}{2}$; the width of the staircase 5 feet 8 inches.

Proceed first to lay down on the plan the width of the landing, then the size of the newel a in its proper position,

Fig. 519.

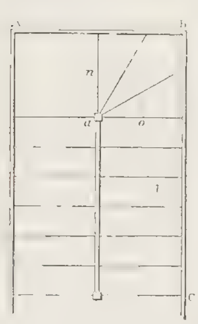
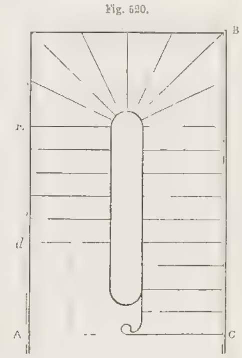


Fig. 520.



the centre of the newel being on the riser line of the landing, which should be drawn at a distance from the back wall equal to the semi-width of the staircase, and at right angles to the side wall. Bisect the last riser $a\ b$ at o, and describe an arc from the centre of the newel, as $o\ n$, on which set out the breadth of the winders; then to the centre of the newel, draw the lines indicating the face of each riser. If there be not space to get in the whole of the steps, winders may be also introduced on the left hand side, instead of the quarter space, as shown.

The next example is a geometrical staircase.

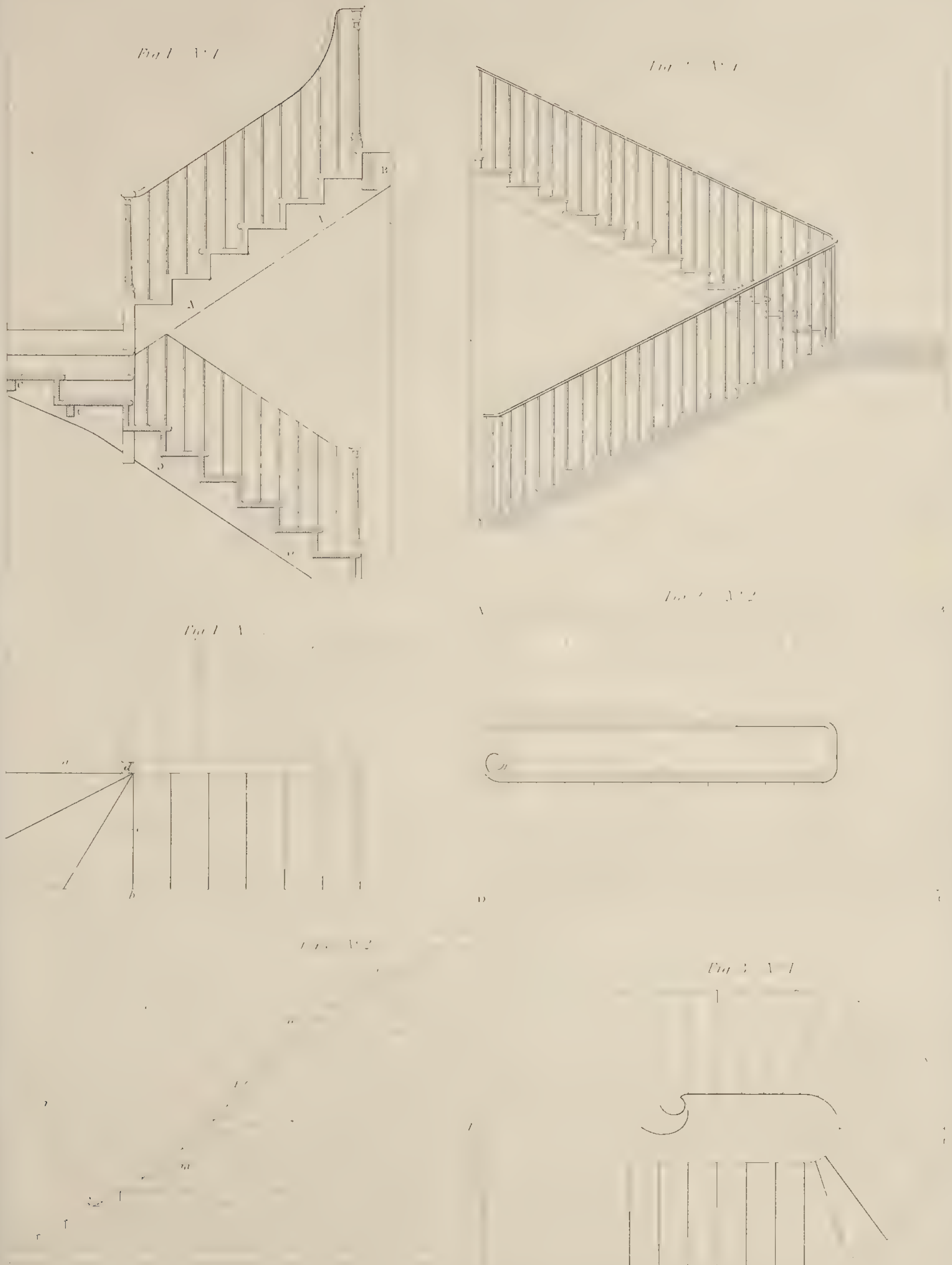
Let A B C D (Fig. 520) be the plan of the walls where a geometrical stair is to be erected, and the line C be the line of the face of the first riser; let the whole height of the story be 11 feet 6 inches, and the height of riser 6 inches, the number of risers will consequently be twenty-three. The number of steps in each flight will be one fewer than the number of risers, and according to the preceding rule the tread should be 11 inches, so if there are two flights there will be twenty-one steps; or if winders are necessary, there will be twenty-two steps in all, from the first to the last riser. Having first set out the opening of the well-hole, or the line of balusters, divide the width of the stairs into two equal parts, and continue the line of division with a semicircle round the circular part, as shown by the dotted line in the figure; then divide this line from the first to the last riser into twenty-two equal parts, and if a proper width for each step can thus be obtained, draw the lines for the risers. This would, however, give a greater width of step than is required; take therefore 11 inches for the width of step, and this, repeated twenty times, will reach to the line d, which is the last riser. There is in this case eight winders in the half space, but four winders might be placed in one quarter space, the other quarter space might be made a landing, and the rest of the steps being fliers, would bring the last riser to the line A C. The usual place for the entrance to the cellar stairs is at D, but allowing for the thickness of the carriages, the height obtainable there will be only about 6 feet, which is not sufficient. At E, in this example, would be a better situation for the entrance to the cellar steps.

PLATES LXXXVIII.—XCIII., XCV.

PLATE LXXXVIII., *Fig.* 1.—Nos. 1 and 2, show a plan and elevation of a newel stair. The first quarter space contains three winders, the next quarter space is a landing; the lower flight is shown partly in section, exposing the rough string D D, and its connection with the bearers C C. The front string A A should be tenoned into the newels below and above.

Fig. 3.—No. 1, shows the plan of a geometrical stair with winders. In the first quarter space, or lower half of the figure, the lines of the steps are drawn to the centre of the well-hole, and this is the usual way of placing the risers; but drawn thus as radii of the circle, they are, obviously, too narrow at the inner end next the well hole, and too wide next the wall, and if two persons were passing each other they would both be forced to use parts of the tread, most inconvenient to walk upon. Further, as the risers of the steps are all of equal height, it follows that the slope or ramp of the string board along the ends of the fliers, from the first to the seventh step, will be much less steep than that which subtends the narrow ends of the winders, and the result will be a very ungraceful knee at their junction. Both of these inconveniences can be overcome by adjusting the steps in such a way as to distribute the inequality amongst them, or as the French term it, by making the steps dance, as is shown in the upper half of the figure. This may be accomplished either by calculation or graphically. By the first method, the step which is in the centre of the circular arc is regarded as a fixed line, and the divergence from parallelism has to be made between it and the extremes either way. But it is not necessary to begin the divergence at the first step, nor indeed is it advisable, and in general the first and last three or four steps are left unaltered, so that they may be perfectly parallel to the landing. Suppose then that the divergence is fixed to commence at the fourth step, it becomes necessary to distribute eight spaces along the centre of the string, commencing at the centre line of the stairs, which, from the centre line to the fourth riser, shall follow some law of uniform progression, say that of arithmetical progression, as being the most simple. The progression then will consist of eight terms, the sum of which shall be equal to the length from the centre to the fourth step. Suppose that its develop-

STAIRS



ment is 66 inches, a length composed of the breadth of three fliers, 4 5 6, namely 36 inches, and the sum of the widths of the ends of the five winding steps, 7 8 9 10 11, namely 30 inches,

Subtracting from	66 inches.
The width of eight steps of the same width as the winders, ...	48 ,,
There is obtained the difference .	18 ,,

from which is to be furnished the progressive increase to the steps as they proceed from the centre to riser No. 4. Suppose these increments to follow the law of the natural numbers 1 2 3 4 5 6 7 8, the sum of which is 36, divide the difference 18 by 36, and the quotient, 0·5 inches, is the first line of the progression, and the steps will increase as follows:—

The end of step No.	11 =	6·5
"	10 =	7
"	9 =	7·5
"	8 =	8
"	7 =	8·5
"	6 =	9
"	5 =	9·5
"	4 =	10
The sum of which is		66

These widths, taken from a scale, are to be set off on the line of balusters, and from the points so obtained, lines are to be drawn through the divisions of the centre line. It is easy to perceive that by this method, and by varying the progression, any form may be given to the curve of the string.

The graphic method, however, now to be described, is preferable to the method by calculation, seeing that it is important to give a graceful curve to the development of the string.

Let the dotted line $s\ m\ p$, *Fig.* 3, No. 2, represent the kneed line made by the first division of the stairs in the lower part, corresponding to the nosing of the fliers, and the upper part $m\ n$ to that of the winders. Bisect the line of the winders $m\ n$ in p, and raise a perpendicular $p\ i$. Then set off $m\ s$ equal to $m\ p$, and make $s\ r$ perpendicular to $s\ m$. The intersection of these two perpendiculars, $s\ r$ and $p\ i$, gives the centre of the arc of a circle, tangential in s and p to the sides of the angle $s\ m\ p$. In like manner is found the arc to which $p\ n$, $n\ o$ are tangents, and a species of cyma is formed by the two arcs, which is a graceful double curve line without knees. This line is met by the horizontal lines, which indicate the surface of the treads, the point p being always the fixed point of the centre step, the twelfth in this example. Therefore, the heights of the risers are drawn from the story rod to meet the curved line of development, $s\ p\ o$, and are thence transferred to the baluster line on the plan.

Fig. 2.—Nos 1 and 2 show the plan and elevation of a well-hole stairs, with a landing in the half space. The well-hole is here composed of two circular quadrants connected by a small portion of straight line; this figure is not so graceful as the perfect semicircle in *Fig.* 3, No. 1, but it allows more room on the landing.*

PLATE XC. *Fig.* 1.—Nos. 1 and 2 are the plan and elevation of a geometrical stair, composed of straight flights, with quarter-space landings, and rising 15 feet 9 inches.

The first flight is shown in *Fig.* 1, No. 2, partly in section, exhibiting the carriage $c\ c$, T the trimmer joists for quarter space, and V the trimmer joists of the floor below, with the lower end of the iron baluster fastened by a screw and nut d, at the under side of the trimmer joist V.

Fig. 2.—No. 1, exhibits the plan, and No. 2, the elevation of a geometrical stair, with straight flights connected by winders on the quarter spaces.

PLATE XCI.—*Fig.* 1 is a plan, and *Fig.* 3 an elevation of a geometrical stair, with a half space of winders. The positions of the rough strings or carriages are shown on the plan by dotted lines, $e\ g$, $e\ f$, $h\ i$, $f\ k$. This is a simpler mode of forming the carriages of stairs than that generally practised; having fewer joints it is also stronger. It is fully illustrated and described as applied to the more intricate example of elliptical stairs in Plate XCII.

Fig. 2 shows the plan, and *Fig.* 4 the elevation of a geometrical stair with part winders, and part landing, well adapted for a situation where a door has to be entered from the landing. The line A B on the plan shows the situation where the principal carriage should be introduced.

PLATE XCII. exhibits a plan (*Fig.* 1, No. 1) and elevation (*Figs.* 1 and 2) of an elliptical stair with winders throughout. On the plan is shown the position of the carriages for such a stair, and we shall now describe the formation of such carriages.

PLATE XCIII. represents the formation of carriages for the elliptical stairs in Plate XCII. *Fig.* 1 is the longest carriage, or rough-string, and is formed of one deal, 11 inches wide by 3 or 4 in thickness; its length of bearing betwixt the walls is about 15 feet. To find the best position for the carriages, lay a straight edge on the plan, and by its application find where a right line will be divided into nearly equal parts by the intersection of the risers. The object of this will readily be understood, if it is considered that in a series of steps of *equal* width and risers of equal height, the angles will be in a straight line, whereas in a series of *unequal* steps and *equal* risers, the angles will deviate from a straight line in proportion to the inequality in the width of steps. Notwithstanding the inequality in the width of steps, which thus often occurs, it seldom happens that carriages may not be applied to stairs, if their situation be carefully selected by the means above mentioned. The double line A B is taken from the plan (*Fig.* 1, No. 1, Plate XCII.), with the lines of risers crossing at various angles of inclination. These lines represent the back surface of each riser, according to the number on each. The double line A B will therefore be understood as representing the thickness of the piece. Lines drawn from the intersections of each of the risers perpendicularly on A B (*Fig.* 1, Plate XCIII.), will present the width of bevel which each notching will require in the carriage at the junction of the wall. No. 8 crosses very obliquely; No. 9 with somewhat less obliquity; No. 10 with still less, and the obliquity continually diminishes, till at 13 the crossing is at right angles, presenting only one line. The remaining numbers are bevelled in the reverse direction, gradually increasing to No. 19, where the carriage enters the wall. The complete lines show the side of the carriage next the well-hole, whilst the dotted lines represent the side next the wall. The most expeditious method of setting out such carriages is to draw them out at full size on a floor. Having first set out the plan of the stairs

* For description of Plate LXXXIX., see pages 200, 201, and 207.

at full size, take off the width of every step, in the order in which it occurs, marking that width, and at right angles thereto draw the connecting riser, thus proceeding step by step, till the whole length of the carriage is completed; next set out one side of the carriage as a face side, and square over to the back, allowing the bevel as found on the plan; then, with a pair of compasses, prick off to the under edge at each angle, for the strength; this will define the curvature for the underside with its proper wind, to suit the ceiling surface of the stairs. The bearer, C D, *Fig.* 1, No. 1, Plate XCII., is a level piece wedged in the wall, with its square end abutting against the side of the carriage, A B. The dotted line on the upper side of the carriage, *Fig.* 1, Plate XCIII., and the straight dotted line on its under side, are intended to show the edges of an 11-inch deal previous to its being cut; the shaded part at each end shows its bearing in the wall; at the riser 18 is shown a corpsing, to receive the lower end of the carriage, *Fig.* 3, C L; and at the riser 16, a similar corpsing to receive the carriage, *Fig.* 4, G H; *Fig.* 2 is the carriage, E F *Fig.* 1, No. 1, Plate XCII., parallel with A B, *Fig.* 1, against which the front string is nailed. Each of the last mentioned is formed in the same manner as the one already described.

This method of forming the carriages of stairs is not yet much practised. It was introduced by the author more than thirty years since, and has given greater satisfaction than the more laborious process of framing for every step, which is not only weaker from the greater number of joints, but is also more expensive. It is now gradually coming into use.

PLATE XCV. exhibits a stair winding round a large cylindrical newel. *Fig.* 1 is the plan, and *Fig.* 2 the elevation. The lower part of the newel is composed of cylindrical staving, of 2-inch plank, into which the risers and bearers to each step are fixed, the detail of which is better seen in *Fig.* 4, drawn to a larger scale. The manner in which the steps and risers are put together is shown in *Fig.* 3; the risers are grooved, and the steps tongued into them. This figure shows the ends of the steps before the last thin casing of string board is fixed. They are united by a band of iron screwed to the bearers throughout the entire length. This kind of construction has a near resemblance to the method for carriages that has been much in use, and called framed carriages for well-hole stairs, the objections to which are stated above.

METHOD OF SCRIBING THE SKIRTING.—PL. LXXXIX. *Fig.* 4 shows the method of scribing down skirting on stairs. The instrument used for this purpose is shown in two positions, A and B. It is something like a bevel in form, but has a slider with a steel point at the end; this slider moves steadily in collars, so that while the steel point rests on any point on the stairs, another point on the slide denotes on the skirting board the corresponding point, thus remedying a defect of the common compasses by maintaining always a parallel motion.

Fig. 5 is another view of the same instrument, showing the mortise in which the slide works.

STRINGS.—*Fig.* 6 shows a portion of a string board for the steps (*Fig.* 8); the middle part being a flexible veneer intended to be bent on a cylinder of a suitable curvature, and blocked on the back by pieces in a perpendicular position.

Fig. 9 is the string board in development for the smaller end of the winders.

Fig. 7 a more enlarged view of the same, showing the mode of easing the angle by intersecting lines.

In circular strings, the string board for the circular part is prepared in several different ways. Each of these will now be described, the first being that adopted in *veneered strings.*

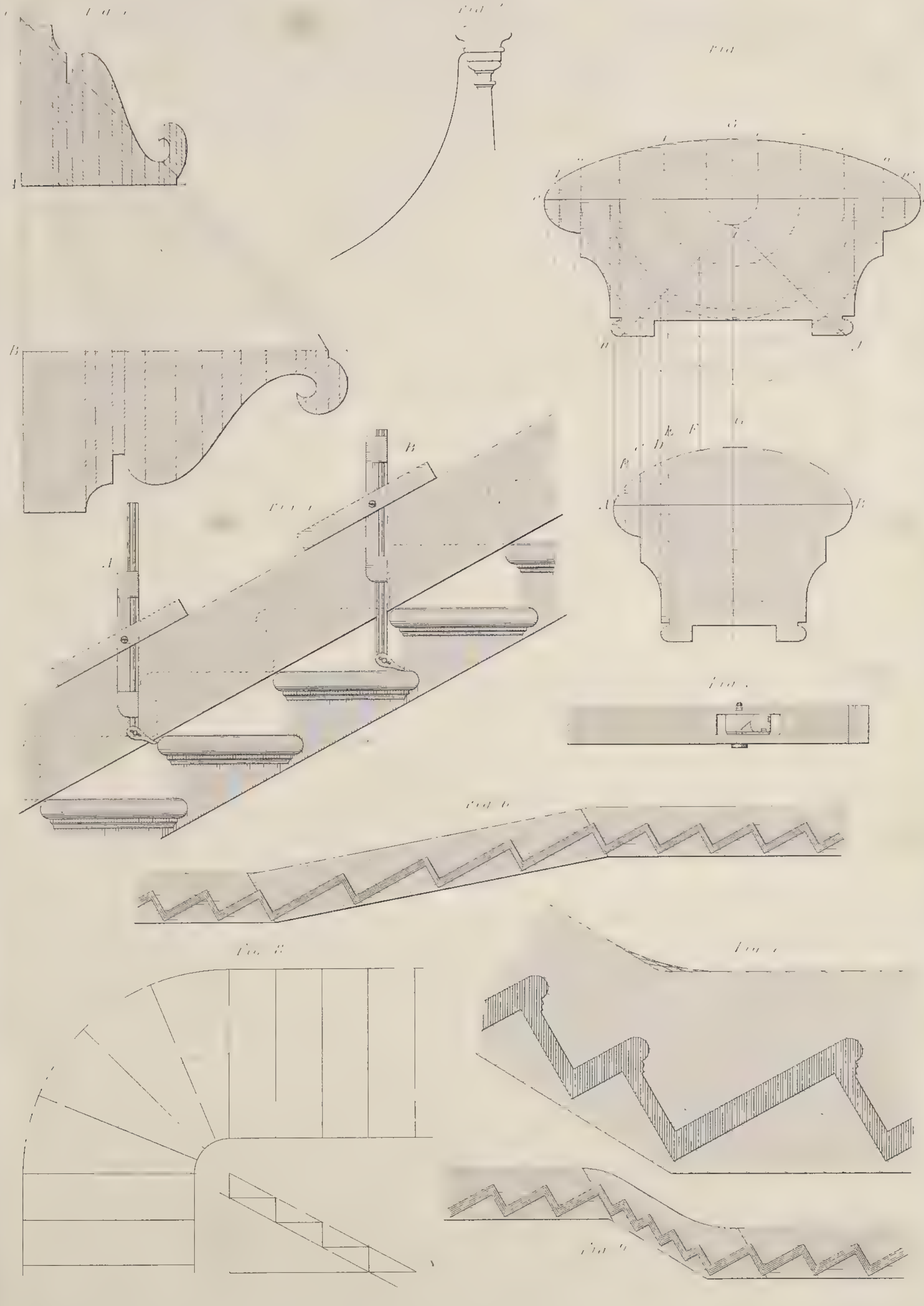
One indispensable requisite in forming a veneered string, is called by joiners a *cylinder;* it is, however, in fact, a semicylinder joined to two parallel sides. An apparatus of this kind must first be formed of a diameter equal to the distance betwixt the faces of the strings in the stairs.

Take some flexible material, as a slip of paper, and measure the exact stretch-out of the circular part of the cylinder, from the springing line on one side to the springing line on the other. Lay this out as a straight line, on a drawing board; then examine the plan of the stairs, and measure therefrom the precise place of each riser coming in contact with or near to the circular part of the well-hole as it intersects on the line of the face of the string, and also the distance of such riser from the springing-lines. These distances should all be carefully marked on the slip of paper, and transferred to the drawing-board; then, with the pitch board, set out the development of the line of steps, by making each step equal to the width found, and connecting with it at right angles, its proper height of riser. When the whole development has been set out on the drawing-board, mark from the angles of the steps downwards, the dimension for the strength of carriage; by this means it will be seen what shape and size of veneer will be required. The whole of the setting out must now be transferred to the face of the veneer; then with the point of an awl prick through the angles of the steps and risers, and trace the lines on the back, as well as on the front. The veneer must now be bent down on the cylinder, bringing the springing lines and centre lines of the string to coincide as exactly as possible with those of the cylinder; the whole string must then be carefully backed by staving pieces glued on it, with the joints and grain parallel to the axis of the cylinder. The lines on the back of the string will serve to indicate the quantity of the veneer to be covered by the staving. The whole must be allowed to remain on the cylinder, till sufficiently dry and firm. It is next fitted to the work, by cutting away all the superfluous wood as directed by the lines on the face of the veneer, and then being perfectly fitted to the steps, risers, and connecting string; it must be firmly nailed both to the steps and risers, and also to the carriages. Each heading joint in the string should be grooved and tongued with a glued tongue.

There is another method of gluing up the strings sometimes practised. In this the string is set out as before described, but instead of using a thin veneer, an inch board is taken, on the face of which the development of steps, risers, springing, and centre lines must be carefully set out as before. The edge of the board must be gauged from the face, equal to the thickness of a veneer, which would bind round the cylinder; the string must then be confined down on the work-bench, and grooves made by a dado grooving plane on its back in the direction of the riser, and at about half an inch distant from each other, till the whole width of the cylindric surface is formed into a

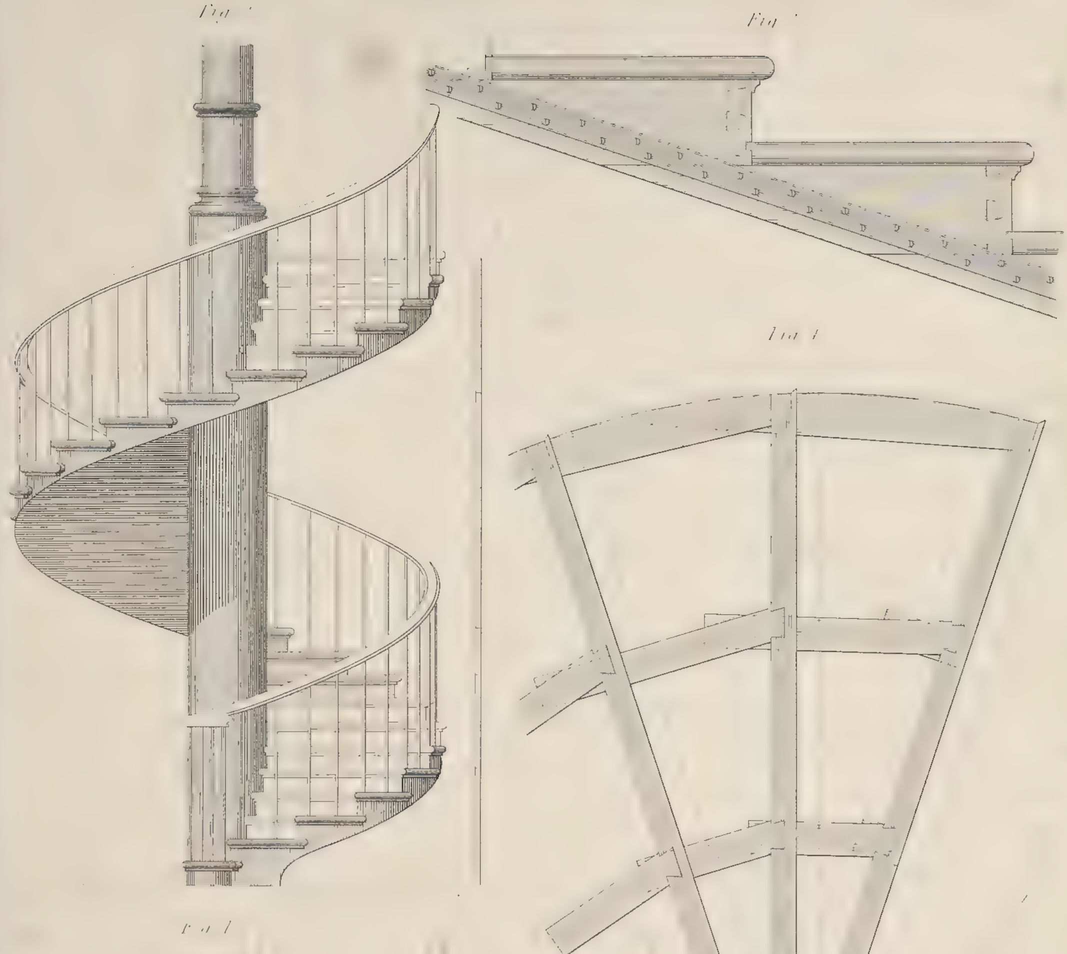
STAIRS.

ENLARGING AND DIMINISHING BRACKETS DRAWING MITRE CAP, SCRIBING, SKIRTING &c.



STAIRS.

CIRCULAR STAIRS.



J. White del.

regular succession of grooves and projections; the string must then be bent on the cylinder, and the grooves filled with small bars of wood, carefully glued in. When dry, this is to be fitted to the stairs, as in the former method.

Another method is making staves hollowed on the face to the curvature of the well-hole, and setting out as much of the string on each piece as will cover its width, then gluing the staves, edge to edge, without any veneer. This method, though *expeditious*, is not *safe*.

A fourth method is sometimes practised, when the curved surface is of great length and large sweep, as in the back strings of circular stairs. In this a portion of cylindric surface is formed on a solid piece of plank, about three or four feet in length; and the string, being set out on a veneer of board sufficiently thin to bend easily, is laid down round the curve, with such a number of pieces of like thickness as will make the required thickness of the string-board. In working this method, the glue is introduced between the veneers with a thin piece of wood, and the veneers quickly strained down to the curved piece with hand-screws. A string can be formed in this way to almost any length by gluing a few feet at a time, and when that dries, removing the cylindric curve and gluing down more, till the whole is completed.

The manner of jointing the staves is shown in Plate XCIII., *Fig.* 5, where a bevel is set with the tongue in the line of the radius, whilst the stock coincides with the back of the stave piece. *Fig* 6 also shows how a back string is formed for the stair in Plate XCII., and a base moulding formed for the same in thicknesses, and applied to the string.

Fig. 7, No. 1, Plate XCIII., shows a portion of front string with bracket, and the mitred end of a riser at *a*. No. 2 shows the back of the same riser and how it is shouldered and mitred to receive the front string and bracket; B shows the thickness of the front string, A the carriage, C the thickness of the tread, *d* the hollow, and *e* the end of the bracket.

Diminishing and Enlarging Brackets. — Plate LXXXIX. *Fig.* 1. To diminish the bracket of the fliers to suit the winders, make one of the fliers marked B, the base of a right-angled triangle, and setting off any convenient distance, B C, for the perpendicular, draw a line from the extreme point of the bracket, to form the hypothenuse of the triangle; set A, the length of the shorter bracket required to be drawn, as a perpendicular, under the hypothenuse; draw ordinates through each member of the original bracket, and through the points of their intersection with B, draw lines converging to the point C. The intersection of these with the line A will divide it for the corresponding set of ordinate lines, which draw, and make equal respectively to those on the line B; trace the contour through the various points thus obtained, and the bracket A will be produced. To enlarge a bracket, it is only necessary to reverse the process by making the shorter bracket, as A, the base of the triangle, producing from it the perpendicular and hypothenuse. This procedure is so obvious, that no detailed description is necessary.

HANDRAILING.

Plates XCIV., XCVI.—C.

Although many authors had written on the subject of handrailing before the time of Mr. Peter Nicholson, the methods described by them for producing the face mould were erroneous in principle, and attended with great waste of material. The merit of introducing a better system is due to Mr. Nicholson, who taught the true theory of cylindrical sections, and illustrated it by practical solutions of the problem of producing the section of a cylinder through any three points on its surface.

In the following treatise, the author, in illustrating the same theory, has introduced methods of solving the problems, which will be found less intricate and easier understood than those of Mr. Nicholson, and, what is not less important, more readily applied in practice. The difference between the two methods will be described in the sequel.

Definitions.—In the following article, there will be frequent occasion to make use of certain terms which it is of importance to have fully understood.

The *horizontal*, or *ground plane*, is that plane on which the plan is drawn.

The *vertical plane* is any plane considered as standing perpendicular on the ground plane.

The *oblique plane*, *cutting plane*, or *plane of the plank*, is that plane on which the mould of the rail is produced.

The *trace* of any plane is a line forming the termination of one plane and its junction with another; thus the angle of a block of marble is the *trace* of the plane of any one of its sides on another side which it meets. The *trace* therefore is a line, and the only line which can be drawn common to either of two planes, meeting each other at an angle.

A *cylinder* is a solid, described by geometricians as generated by the rotation of a rectangle about one of its sides, supposed to be at rest; this quiescent side is called the *axis* of the *cylinder*, therefore the base and top of the cylinder are equal or similar circles.

A *prism* is a solid, whose base and top are similar right line figures, with sides formed in planes, and rising perpendicularly from the base to the top.

The *cylinder*, so called by *joiners*, is a solid figure, compounded of the two last-mentioned figures; its base is composed of a *semicircle* joined to a *right-angled parallelogram*. This last compound figure is intended whenever the word *cylinder* occurs in the following article, unless the word *geometrical* be prefixed.

Of the Construction of the Falling Mould.—The height of the handrail of a stair, as the following considerations will show, need not be uniform throughout, but may be varied within the limits of a few inches, so as to secure a graceful line at the changes of direction. In ascending a stair the body is naturally thrown forward, and in descending it is thrown back, and it is only when standing or walking on the level that it maintains an upright position. Hence the rail may be with propriety made higher where it is level at the landings, the position of the body being then erect, than at the sloping part, where the body is naturally more or less bent.

The height of the rail on the nosings of the straight part of the stairs should be 2 feet 7½ inches, measuring from the tread to its upper side; to this there should be added at the landings the height of half a riser.

In winding stairs, regard should be had, in adjusting the height of the rail, to the position of a person using it, who may be thrown further from it at some points than

at others, not only by the narrowing of the treads, but by the oblique position of the risers. Take, for example, the elliptical stairs (*Fig.* 1, No. 1, Plate XCII.), and suppose the rails of uniform height. A person in ascending, with the foot on the nosing of steps 6 or 7, will find the rail lower to the hand than when standing on the nosings of 19 or 20. The risers of steps 3, 13, and 23 are square with the rail, while those of the other steps are more or less oblique. In such a case it is advisable to make the rail of the average height over 3, 13, and 23, to raise it several inches higher at 7, and to depress it to an equal extent over 19 and 20; to raise it, also, at the top of the stairs, the more especially as the easing of the rail will tend to lower it there. It is seldom that the rail will require to be lowered below the assumed standard more than 3 inches, or raised above it more than 4 inches, and unless these variations in the height are adjusted in accordance with the foregoing considerations, the effect will be very disagreeable.

It is necessary to guard the reader against the common error of raising the rail over winders, especially such as are of steep pitch. The height should be uniform, except in the instances adduced above.

The falling mould (*Fig.* 1, Plate XCIV.) is given in strict agreement with Mr. Nicholson's method, but it is quite at variance with the rule just named.

The Section of a Cylinder.

Plate XCVI.—If any cylindric body, as A B O (*Fig.* 1), standing on a horizontal plane, be cut by an oblique plane, V O *p*, it is obvious that a third or vertical plane, V P B *p*, may be so applied to the cylinder, that it shall not only be at right angles to the ground plane, but also to the plane of section. It can also be easily shown that on such a vertical plane the oblique plane would be projected, according to the rules of projection, as a right line; for, if the position of the oblique or cutting plane can in any way be defined, then the trace of the oblique plane, on its line of intersection O *p* on the ground plane, can be known, and any vertical plane standing at right angles to the trace of the oblique plane O *p*, will be one on which the trace of the oblique plane will be projected as a *right line;* that is, the representation of the plane O *p* on V *p* will be simply a geometrical line; consequently the vertical plane, by construction, is at right angles to the ground plane, and also to the oblique plane. It is evident, then, that if any figure whatever be described on the ground plane, and it be required to describe such a figure that its various parts in every point shall be immediately over the figure on *h p*, nothing more is necessary than to draw lines through the various parts of the figure on *h p*, perpendicular from P B. Continue those lines perpendicularly upon the vertical plane V *p*, and return them on the oblique plane; and then measure on those lines from the line V *p*, the same each to each on the plane V O *p*, as the corresponding lines on the ground plane; thus, the line V 6 will be made equal to P D, the line 5 equal to C, and so of any other line. Those lines are called ordinate lines, and the method here described is called tracing by ordinates. It is thus particularly described, because unless the process be perfectly understood by the learner, he cannot know anything of the way of producing the section of a cylinder or the face-moulds for handrails geometrically.

The manner of obtaining such face-moulds will now be described.

To produce the section of a cylinder through any three points on its convex surface.

Figs. 2, 3.—First draw the plan of the cylinder, or part of the cylinder, as A B C. Let A be the lowest point in the section, B the seat of the intermediate height, and C the seat of the greatest height. The height on A is nothing, and is therefore a mere point on the plan; the height on the point B is equal to *b h*, and the height on C is equal to C *p*. These heights are sometimes called the *resting points.* Draw a right line from A, the seat of the lowest point of the section, to C, the point on the plan agreeing to the highest point of the section; draw C *p* and make it equal to the greatest height of the section; complete the triangle A C *p* by drawing the line A *h p*. Take the intermediate height and apply it to the triangle wherever it can be applied, as a perpendicular under the line A *p*; in other words make *h b* parallel with C *p*, and equal in length to the third or middle height; then draw the line from *b* to B, the seat of the middle height, and it will be the leading ordinate; then at right angles with B *b*, and touching the convex line of the plan of the cylinder, draw the line *a* B D—this line is the trace of the vertical plane. Draw the line C *p* at right angles to *a* B, and passing through the point C on the plan, make D P equal to C *p*; complete the triangle D P *a* by drawing the line P *a*; continue the line *b* B until it intersect the line *a* P at 2. This triangle completes the representation of the vertical plane. Nothing more now remains to be done but to draw the ordinates *c d* and *e* parallel to D P; to square out from the line *a* P the corresponding ordinates 1 2 3 4 5 6, and to make them respectively equal to the corresponding ordinates on the plan; thus 6 P is equal to D C, 5 is equal to *e*, 4 equal to *d*, 3 equal to *c*, 2 is equal to B, and 1 *a* is equal to *a* A, and the mould for the oblique plane will be completed by tracing a line through the points 1 2 3 4 5 6. The angle *a* P D is what is usually called the pitch of the plank, the use of which will be explained hereafter. In order further to demonstrate this subject, consider the figure of the ground plan to be drawn on a level plane, and *a* P D to stand vertically on its trace *a* D; then suppose the oblique plane to be turned on its trace *a* P, so as to form a right angle with the vertical plane, and it will follow of necessity that the point 1 will coincide with the point A; and the point P being thereby elevated to the full height of the section P 6 will be brought into a position parallel with D C; 6 P being equal to D C, the point 6 will of necessity be in the exact situation of the highest point of the section; so also the ordinate 2, being equal to the ordinate B and parallel to B, must bring that point equal to the intermediate height; so also of all the other ordinates: therefore the mould 1 2 3 4 5 6 is the section of the cylinder to the three heights and points required.*

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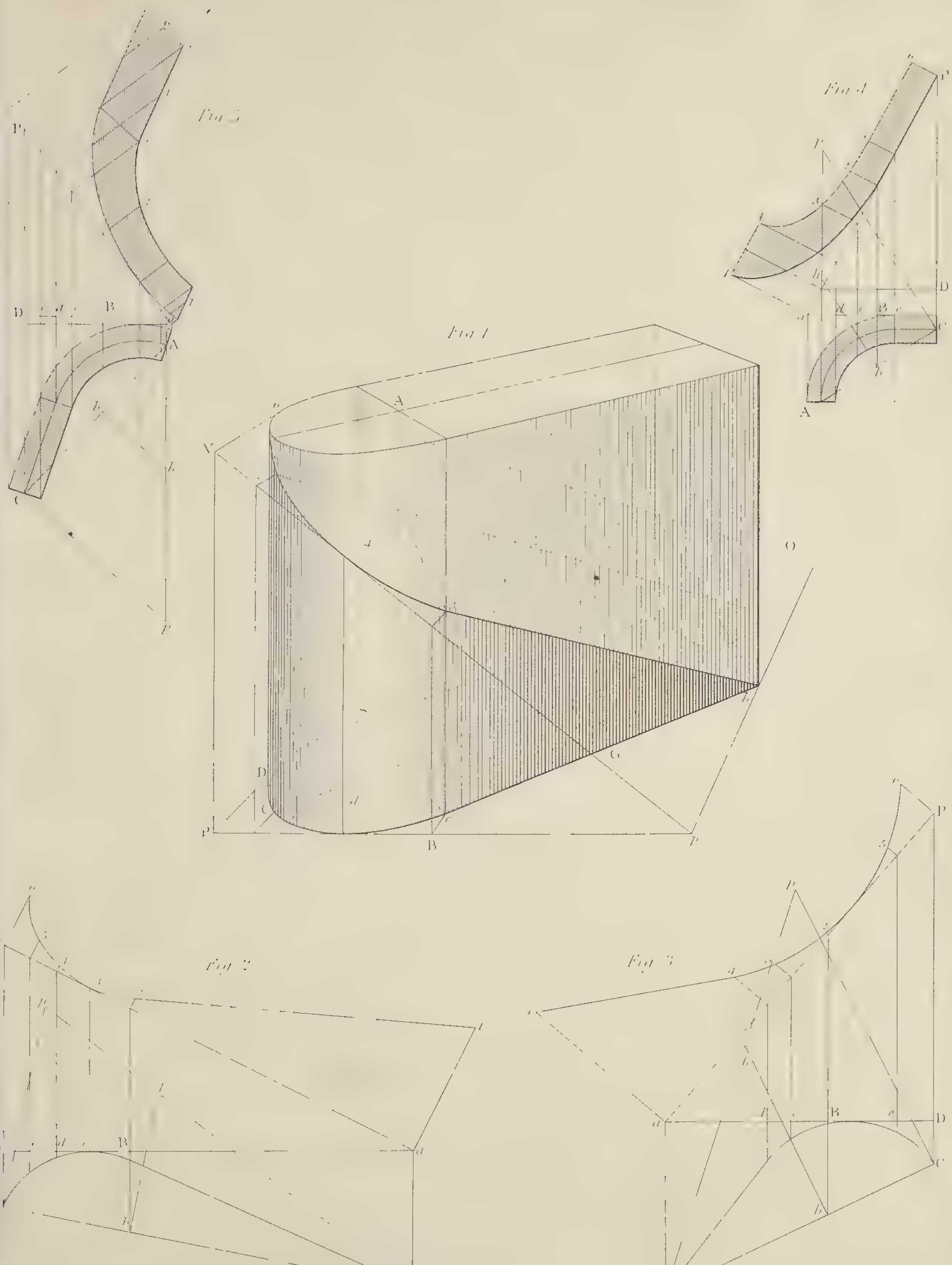
* The author, when a lad, in 1824, heard a fellow-workman read a passage from Mr. Nicholson's work, *The Builder*, and was struck with the words: "Section of a cylinder through any three given points." He was at that time familiar with the method of producing groins, angle ribs, brackets, &c., by ordinates, and at once proceeded to solve the problem indicated in Mr. Nicholson's words.

HAND RAILING.

SECTIONS OF SOLIDS.

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Figs. 4 and 5 differ nothing in principle from that we have already described. The centre line of the plan of the rail is here substituted for the line A B C in *Figs.* 2 and 3. Draw the line A C, connecting the seats of the highest and lowest points; make C p equal to the greatest height, and at right angles with A C; make b h equal to the intermediate height, and draw the line b B, the leading ordinate, as in the preceding figures; square from it for the base of the section, and make all the ordinates on the plan parallel with the leading ordinate b B. Make D P equal to C p, the height of the section; draw P a, continuing the ordinates to a P; square them out from a P, and make each ordinate on the section equal to its relative ordinate on the plan; draw the figure through the various points 1 2 3, &c., and the moulds will be completed. In drawing the first triangle A C p the line C p may be made equal to the *whole* height, or to any fraction of the height, provided the intermediate height be drawn in the same manner; for it is evident that if the perpendicular C p be lengthened or shortened, the perpendicular b h will be lengthened or shortened in the same proportion; and it will sometimes be found more convenient to use a part than the whole of the height, as will be seen in constructing the moulds, Plate XCVII. Other means might also be adopted of finding the trace of the oblique plane on the ground plane, one of which we have shown in Plate XCIV., *Fig.* 2.

Before proceeding further, it may be well, in a few words, to describe the leading points of difference between Mr. Nicholson's method and that here taught.

In Mr. Nicholson's method two bevels are required in cutting the plank, and the ordinates are bevelled both on the plan and on the oblique plane.

The seat points of the heights used are: — one at each corner of the mould and one on the convex part of the rail.

The heights are measured to the top side of the falling mould for the lower wreath, and to the under side downwards for the upper wreath.

The vertical plane, from which the ordinates are traced, is generally, if not always, made to pass through the inner angles of the joint lines of the plan.

The oblique plane, on which the face mould is produced, is sometimes at a right angle, sometimes at an acute angle, and sometimes at an obtuse angle to the vertical plane. This is what he calls the spring bevel, and it is necessary to bevel the plank in accordance with this before the pitch bevel can be applied.

In the method here taught the pitch bevel only is used, and the ordinates are squared on the plan and on the oblique plane. The pitch bevel of this method is therefore equivalent to the two bevels of the other.

The seat points of the heights are taken on the centre line of the rail, and the heights are taken to the centre line of the falling mould; the trace of the vertical plane is always square with the trace of the oblique plane, consequently the use of the spring bevel is not required, the piece having only to be bevelled at once to the pitch bevel.

Fig. 2, Plate XCIV., is intended to illustrate the difference between the two methods, No. 1 showing the method of the author, and No. 2 that of Mr. Nicholson; and in order that the illustration may be complete, the heights or resting points in both figures are taken in accordance with the latter method.

Plate XCIV., *Fig.* 2, No. 1.—A base line is drawn from 1 to 3, connecting two of the resting points, and parallel therewith a line is drawn through 6, which is the intermediate resting point, indefinitely towards the point 8; the line 1 2 is drawn perpendicular to 1 3, and equal in height to the height of the section or a fraction of the same—in this case one-fourth—it being taken, according to Mr. Nicholson's method, to the top of the rail. The perpendicular 3 4 is made equal to the intermediate height, or the same fraction of that height (one-fourth); the line 2 4 is drawn through the point 4 indefinitely, the line 1 3 is continued to intersect 2 4 in 5, and the line 7 8 is drawn parallel with 2 5, intersecting 6 8 at the point 8, giving the line 8 5 as the line of the trace of the plank on the ground plane. This gives a trace or leading ordinate precisely parallel with that we have adopted; but we think it is far from being so direct in its application to the subject as that we have generally used. Mr. Nicholson's most usual method of finding the trace of the oblique plane is shown in *Fig.* 2, No. 2, where the seats and heights are the same as in No. 1; P 2 being the greatest height, T 6 the intermediate height, and 9 V the least height. The line P O is drawn connecting the corners of the plan mould; P 2 is drawn perpendicular to P S; 6 T is parallel to P 2, and equal to the intermediate height; V S is parallel to P 2, and equal to the lowest height; 2 V is drawn indefinitely till it meets a line drawn through the points P and 9 in Q, 6 L is drawn parallel to P Q, and T L parallel to 2 Q; this gives the trace of the plane L Q, which is continued to O, where it meets the line P S; then draw the ordinate 9 on the plan, meeting P O where the ordinate g on the vertical plane is made equal to 9 V; g 2 is then drawn, meeting P S in O. This is Mr. Nicholson's most usual and roundabout method of finding the trace of the oblique plane; but besides this it is also necessary to find the leading ordinate on the oblique plane. To do this, draw S M perpendicular to 2 O, and from the point O describe the arc L M, and draw O M, the leading ordinate. This method requires a spring bevel, which is shown at O, and is found by setting one foot of the compass in S, and extending the other to the line O 2, making the portion of the arc there seen meeting the line P O; from the point of intersection in P O, draw a line to L, and the spring bevel will thereby be produced. The leading ordinates being found, all other ordinates are drawn as parallels, and the mould is traced according to the figures.

We have thus contrasted the method of Mr. Nicholson by bevelled ordinates with our own method by squared ordinates, to satisfy the reader that, *if the same heights and seats of heights are used, the same mould is produced by squared as by bevelled ordinates.* The plan mould on the left is exactly the same as that on the right;

He succeeded in his endeavours, and practised his own system for a year without being aware what amount of affinity existed between it and that of Mr. Nicholson.

The general method here explained was first taught by the author in Cheltenham in the year 1826, and in other parts of England previous to 1830, in which year he visited the United States of America, and practised and taught this method in the city of Philadelphia, where he resided for more than seven years.

the heights are the same, both being taken from the falling mould *Fig.* 1', each height being taken from the line A to the top of the falling mould in each case. It will at once be seen that the mould is identical, the tracing in one case being from the line on the concave side, and in the other from that on the convex side of the mould.

PLATE XCVII., *Fig.* 1, shows the face mould, and *Fig.* 2 the falling mould of a rail suited to the stairs, *Fig.* 1, Plate XCI. For the falling mould describe the quadrant B 3 (*Fig.* 2) to the radius of the concave side of the rail on the plan, and make D B equal to its development; then set out the lines of steps and risers in the order they occur in the stairs, placing all the risers at their proper situation as to the springing and centre lines; make 1 equal to the last flier, 2 equal to the first winder, 3, 4, 5, and 6 equal to the succeeding winders, taken on the concave curve of the rail; draw the bottom lines of the falling mould, making them touch the angles of the steps excepting where the curved part necessarily leaves them; draw a line for the centre line of the falling mould at a distance from the bottom equal to the half of the depth of the rail, also a line at the distance answering to the top of the rail, and draw lines at right angles through the thickness of the rail for the butt-joint, as at P and A; draw a line through the centre of the lower butt-joint parallel to D B, meeting P B in C; make the line *b h* perpendicular to C *b*, at or near the centre of the length of the falling mould. We shall then have P C for the greatest height, and *h b* for the intermediate height of the section; the lowest point of the section being the point A in the plan, the seats of those points on the plan must ever be in the centre line of the rail. The method of producing the face mould differs nothing from the general method. In *Fig.* 1 draw A C; make C *p* perpendicular thereto, and equal to the greatest height, or to some fraction of the same—in this case it is one third; then draw the hypothenuse *p h* A, and take the intermediate height, or its corresponding fraction one-third, and apply it to form the perpendicular *b h*. From *b* to the seat of the middle height on the plan, draw the leading ordinate *b* B, and square the base of the vertical plane as a tangent to the plan mould; draw all the ordinates on the plan parallel to the leading ordinate, and through as many points as may be needed for the tracing; make P *f* equal to the greatest height, and draw the hypothenuse P *a*, from which square out all the ordinates, making them respectively equal to the corresponding ones on the plan; carry one ordinate through the centre of the plan, and take off the distance of that point, applying it as at *n*. Draw the dotted line *n* 4, and make the butt-joint at 6 by squaring from *n* 4 through the centre of the bevel joint. Make the butt-joint at the straight part by simply squaring it from the side of the mould through the centre of the bevel joint; then trace through the points 1 2 3 4, &c., and the mould will be complete.

The *Figs.* 3 and 4 of this plate are drawn on precisely the same principle, as before described. They are here introduced as a specimen of a wreath of a small well-hole, with a very sharp ascent, the radius of the inner curve being only 3 inches with three winders in the quarter-space. The risers are here supposed to be drawn to the centre, the riser between the last flier and the first winder is consequently identical with the springing line; the same line is also here made the line of the middle height. The falling mould is constructed, as before described, with the undersides touching the angles of the steps, excepting only where made conformable to a fair curve; the height of the section is found, as in the former case, by drawing a horizontal line through the joint line at A, and taking the height from this line to P for the greatest height, both it and the intermediate height being taken to the centre line of the falling mould. A line is drawn in *Fig.* 3, through two of the seat points, namely, A and C; one third of the greatest height is used as a perpendicular, and the same fraction is used for the middle height, *b h*; the leading ordinate is drawn through the seat of the middle height, that is, through the centre of the springing line; the base of the vertical plane is squared from the leading ordinate, and the entire height of the section set up, as P 1, the perpendicular; and having drawn P *a*, and continued and squared out the ordinates, the mould is pricked off by making each ordinate 1 2 3 4, &c., equal to its respective ordinate on the plan. The butt-joint is drawn by squaring it from the line, *n g*, through the centre of the bevel joint. In this case the sharp pitch of the mould produces it a great width at each end; if this were to be cut out of the plank to its proper bevel, C P *a*, it would take at least *twice* the amount of material that would be absolutely needed by the means we shall now point out. Let the centre line be pricked out on the mould, parallel with which draw the dotted line, shown on the same. Now if the mould be laid on the plank in this form it will appear as at *Fig.* 5; this may be cut quite square out of the plank, and will be quite sufficient to produce the rail in the most perfect shape; C D shows the edge of the plank, the oblique line C D being the proper bevel just mentioned, which is to be drawn on the edge of the plank; A B is drawn on the mould when in its position in *Fig.* 3, as a parallel to P *a*, and is called the backing line; this line should be drawn on the plank on both sides, and perfectly opposite on each. When the piece has been cut out square, as shown at *Fig.* 5, the point *e* of the mould should be slid to the point C, where the mould is a second time to be marked on the material, keeping the line A B on the mould to agree with the line A B on the plank; then let the mould be applied to the other side of the plank, by bringing the point *e* on the mould to coincide with the point D on the plank, and the line A B on the mould to coincide with the line A B on the piece; mark the piece again in this position of the mould; this is what is called backing the mould, and the piece is now properly lined for wreathing. This is done by placing the piece in the vice with the concave edge upwards, and taking off the superfluous wood down to the lines just described on the surface of the plank. It will, however, be found requisite sometimes to place the mould on the piece, and fix both in the vice together, in order to supply that portion of the line which will be deficient by reason of cutting square through the plank, instead of the old method of bevelling. When the concave cylindric surface is thus produced, the falling mould may be applied. This is done by making the bevel joint line of the falling mould to correspond with the bevel joint line of the piece, while the butt-joint lines of the falling moulds also coincide with the butt-joints of the piece; the butt-joints of the falling mould thus applied will now show the position of the joint

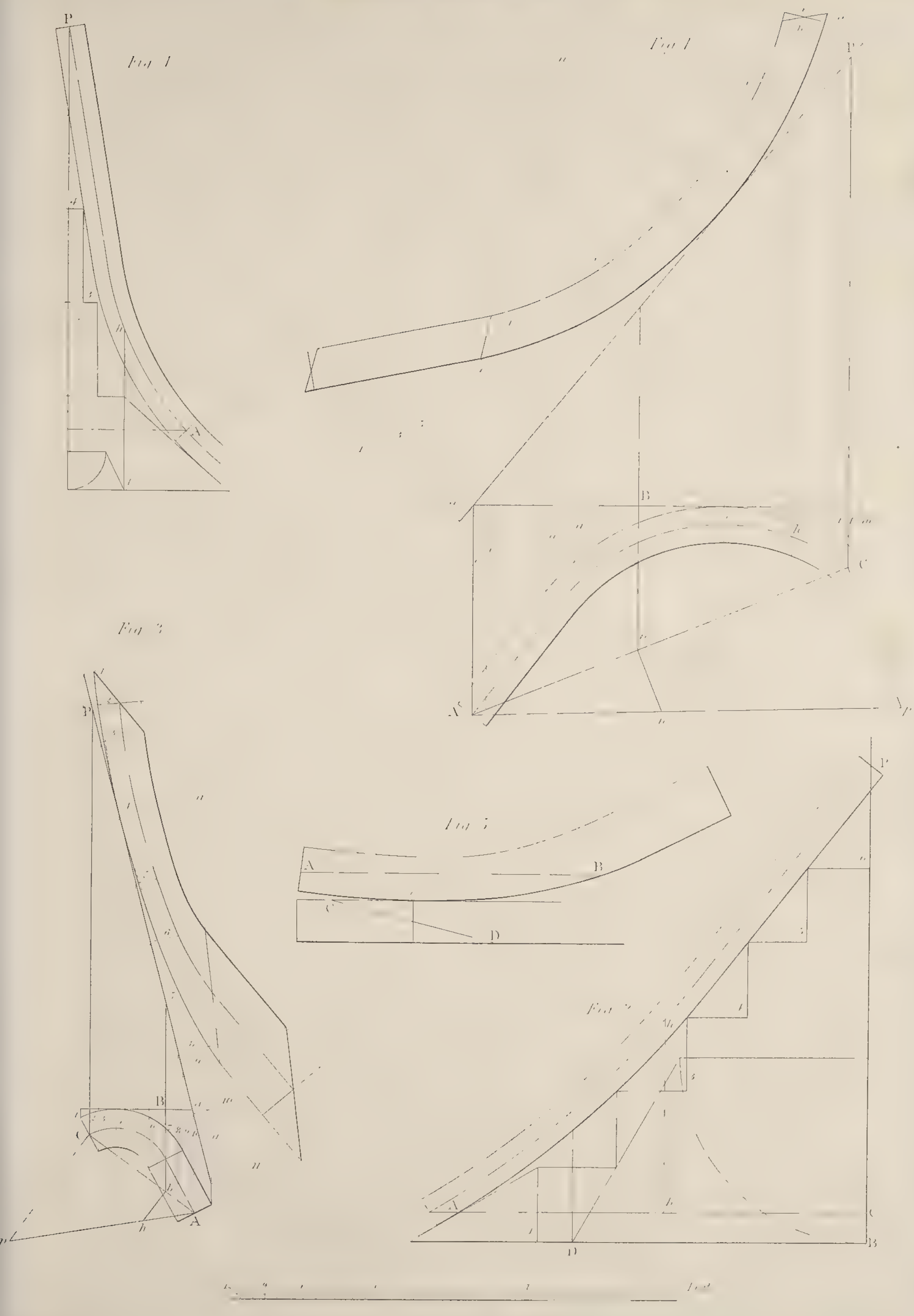
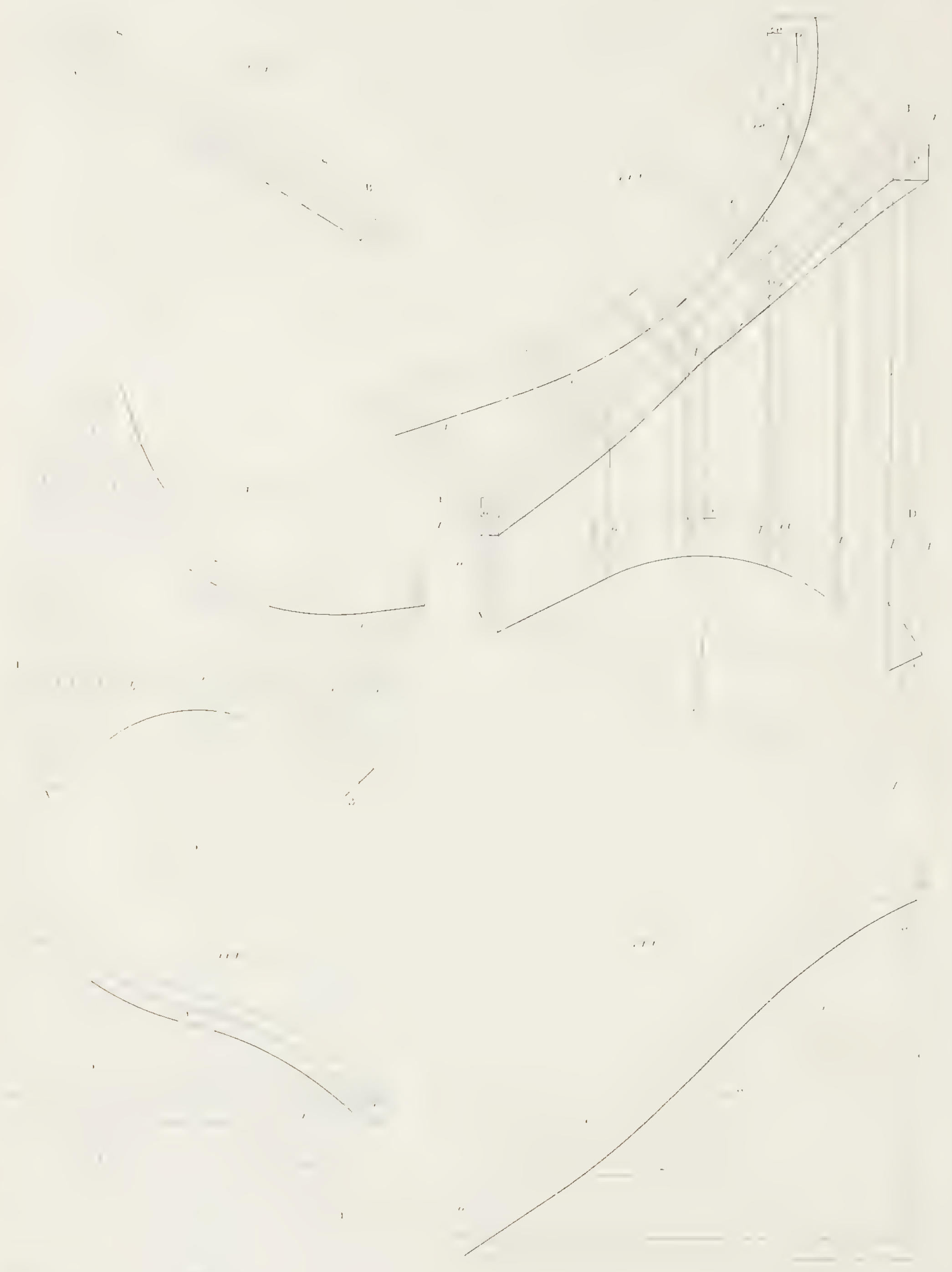


Fig. 1
Fig. 2
Fig. 3
Fig. 4
Fig. 5
P
A
B
C
D



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one way, whilst those of the face mould will show it the other, thus rendering the joint complete; mark on the piece on each side of the falling mould for the under side and top side of the rail; square from the concave surface, both for the top and bottom of the rail, and take off the superfluous wood, using a pair of callipers to gauge off the back side of the piece. What has here been stated will hold good as a general rule; but if the face mould be not much wider than the rail itself, it would be absurd to be at any undue trouble to save material. It will, however, generally be best to cut the piece out square from the plank, and bevel it after in the manner described.

PLATE XCVIII.—*Fig.* 1 is the falling mould, and *Fig.* 2 the face mould of a wreath suitable to the stairs shown at Plate XCI., *Fig.* 2.* *Fig.* 1 shows the stretch-out of A B, the internal curve of the plan. D L is the width of the last flier, 2 3 and 4 are widths of winders, 5 is the half width of the landing; the line L D, *Fig.* 1, is equal to A *g*, *Fig.* 2, or the length of the straight part on the plan; the lines *c d e f* and P, *Fig.* 1, are all at equal distance from each other, and represented at *Fig.* 2, by the portions of radii, *g k l*, &c, drawn across the rail. The position of the oblique plane is found here (*Fig.* 2) by our usual method as shown in the former examples, C *p* being a third of the greater height, and *b h* a third of the intermediate height; and as B is the seat of that height, *b* B becomes the leading ordinate, and *a* B the base of the vertical plane; P *a*, is the pitch of the plank; the lines *t r* and *u s*, show the upper and lower surface of the plank; E F is drawn parallel with *a* P at any convenient distance; *p* and *g* are drawn through each end of the joint line, and continued to the height from the line B *a*, equal to the distance from E to the section of the falling mould at P, *Fig.* 1. This section, or rather the section of the square rail, is thus shown by the small parallelogram at P; in like manner the section of the rail is shown at *f* from the section of falling mould *a f*, *Fig.* 1; the parallelograms *e d c* and *a* are produced in the same manner from *e d c*, and L, in *Fig.* 1. It will now be needful to draw lines through the angles of each parallelogram, and square with the line E F; the mould is then produced by making the ordinate 19 equal to *q* on the plan, and measured from the line E F 18, the same one answering for the top, and the other for the bottom, of the representation of the piece; 20 and 21 are both equal to *p*, on the plan; 14 and 15 are equal to *o* on the plan, 16 and 17 to *n*, 10 and 11 equal to *m*, 12 and 13 are equal to *l*, and the other points are traced in a similar way, and parallelograms are then drawn through the points, as seen in the plate; each of these parallelograms will represent a section of the solid square rail as it would appear on the plane of the plank drawn by orthographic projection; if lines be drawn through these angles, they will represent the square rail; such a mould may be laid on the plank, and the piece cut square out; the piece is then set out on the edge, as shown in the elevation, by the vertical sections of the square rail; the distances of the angles may be measured and set off, and each angle found with great precision, first finding the outside angle of the piece, and then gauging the other angles therefrom.

Fig. 3 of this plate shows the manner of setting out a wreath for such a situation as that exhibited by the landing stairs, *Fig.* 1, on Plate XC. A C is the length of the straight parts at the upper end of the piece, C D the length of the circular, and D B the length of the straight part at the lower end of the piece; make L the landing, equal to the development of C D, and the half steps *r* and *g h*, equal respectively to A C and D B, bisect C D and draw E F; make the perpendicular at *g* equal to half a riser, also the same at C; make the perpendicular at *f* equal to half a riser from L the landing line, to the centre of the rail from this point; set off the half width of the falling mould above *h*, and draw the bottom line of the falling mould by making the hypothenuse lines at *r* and *h*; connect these by a fair curve passing through the proper height at F; draw also the centre line and top of the falling mould. It will be seen that if our usual method of finding the position of the oblique plane were here applied, it would necessarily produce the line *g* as the leading ordinate, for the height F is half the height *k* G, and the base *k i* is bisected by the line F; consequently the hypothenuse should in like manner be bisected by placing the intermediate height; this fact is mentioned to show that there are many cases occurring where a moment's reflection will serve to convince the practical man what the position of the plank should be, without drawing one line. Therefore for the face mould (see *Fig.* 4) bisect the quadrant in *g*, and draw the ordinate *g*, from which square the ordinates from D A, and also from the hypothenuse, and make the ordinates 1 2 3 4, &c., equal to the corresponding ordinates A *b c d*, &c.; and draw the face mould through the respective points to produce the butt-joint square from the side of the rail through the centre of the bevel joint.

The application of the falling mould is shown at *Fig.* 5, the line F of the falling mould (*Fig.* 3) is placed in the position *g*, answering to *g* on the plan, and in the centre of the thickness of the plank; S and S show the springing lines, A and B the bevel joints; a butt-joint is shown at the lower end of the piece: its application will be easily comprehended, and will generally serve for the performance of this work. No example of a perfectly straight falling mould has been given, as it would be superfluous; it will be easily seen, from what has been said, that the leading ordinate in such cases must always fall in the same manner as in the last instance.

PLATE XCIX.—This plate exhibits the manner of producing the falling moulds, and face moulds for scrolls. *Fig.* 1, No. 1 is the face mould, and No. 2 the falling mould, for a small scroll. In tracing moulds of this description, there is no need of any process to find the position of the plank; no better position can be found than that in which a plank would be if laid flat on the nosings of the stairs, and the pitch board gives this angle of inclination. Take the pitch board, and lay the step side of it against the side of the straight part of the level mould A B, and by means of the upper edge of the pitch board, mark off the line *c d*; draw any number of ordinates on the plan mould square with the straight rail, continue them to *c d*, square them out, and prick off the mould by making the ordinates *f g h i k l*, respectively,

* This plate exhibits the method of cutting the wreath out square, as first taught by Mr. Nicholson, but is not contained in his *Carpenter's Guide*.

equal to the ordinates 1 2 3 4 5, on the plan mould, and draw the face mould through the points. This mould may be drawn without using more ordinates than are needed to find the joint, and to show the width of the straight rail. The mould itself is merely a quarter of an ellipsis, both for the inner and outer curve, and its transverse diameter is equal to the diameter of that circle from which it is generated on the plan; therefore if the ordinate *f* be continued till equal to the length of radius, it will represent so much of the transverse diameter, and a line drawn through its extremity parallel to *c d*, will represent the conjugate diameter of the ellipsis, and the mould may be produced by the trammel, or by any of the means explained at pages 23 and 24. The shaded part *a b* shows the piece wrought and in position. The falling mould, No. 2, is produced by making the line *e*, 1 2 3, &c., equal to the line *e*, 1 2 3, &c., in No. 1, on the convex side of the rail. From the top of the ordinate line 1, draw the line *b* to the pitch of the rail, and connect this line to the line 9 *e*, by a fair curve; this forms the bottom line of the falling mould; the top line is drawn parallel to it at a distance equal to the depth of the rail. The ordinates 1 2 3, &c., will now show the height of the rail, in as many points, from the bottom of the scroll. The falling mould, No. 3, is produced by making the line, 1 2 3, &c., equal to the internal curve of the scroll, and the ordinates 1 2 3, &c., on No. 3, equal to the ordinates 1 2 3, &c., on No. 2; the piece is jointed at A on the plan (No. 1) to the level portion of the scroll, the line 5 on the falling mould (No. 3) showing the same as a perpendicular joint, which in this part differs but little from a butt-joint, which might of course be used if preferred. *Fig.* 2 of this plate exhibits the side view of two pieces of handrail of similar character to the scroll pieces just described, but are here shown as applied to a landing, *m* being the landing, *o* the riser, and *n* the step below; whilst *l* shows the riser, and *k*, the step above. Such a landing may be seen in plan at C, *Fig.* 1, Plate XCI., being the top of the first flight of stairs. The risers in this case do not pass through the centre of the well-hole; they are so arranged that the centre B of the rail on the return shall be precisely half a step from the line of risers, *l o*. By this arrangement the piece of rail in this part is of the simple kind just mentioned, less indent of the well-hole into the landing is made, and the rail itself has a better appearance than when a greater amount of it is thrown on the level at the landing. The pitch board is applied with its step side against the side of the plan mould, as at A, and the pitch line produces the line A *a*. Draw all the ordinates *a b c*, &c., parallel to the riser line of the pitch board, and return them on the plane of the mould or plank at right angles to A *a*; make the ordinates *a b c*, &c., equal to the ordinates 1 2 3, &c., on the plan, and draw the mould. This mould, as also the preceding one for the scroll, must be bevelled by the pitch board. Lay, therefore, the hypothenuse of the pitch board to coincide with the surface of the plank, and the riser line of the board will give the bevel on the edge of the plank for backing the mould; this will be better comprehended by the position the piece will have when placed in the work, as shown by C D and E F.

In *Fig.* 3, is shown another and somewhat more expeditious method of working. Let B *c* be the plan mould, with its centre line as shown, and *h e d* the pitch; square out the line *d f* and make it equal to *e c*; then square out from the ordinate *h*, making it also equal to *e c*. The semiconjugate and semitransverse diameters of the elliptical mould will thereby be obtained, and it may be drawn by the trammel, or by any of the methods already mentioned. It is possible, by thus working to the centre line only, to make the rail without cutting it out one-eighth of an inch wider in any place than its *exact* width.

Fig. 4 shows the same piece cut out from the square plank; the end is then, by the use of the pitch board, to have the line *a* drawn through the centre of its thickness; which enables us to draw the centre line of the mould *f* (No. 1) on the piece, as shown by the curve line at *a*. By using a pair of callipers the vertical sides of the rail may be readily produced, and the bottom and top squared from them.

Fig. 5 shows, at No. 1, the scroll adapted for such a stair as the elliptical stair, Plate XCII., or wherever a scroll comes immediately in connection with winders. First decide at what point on the plan mould the scroll shall come to its level position; and as the plank is usually about ½-inch more in thickness than the rail is in depth, it will be possible to obtain that extent of rising in the first part or level portion of the scroll; this is supposed to be at the point *g*, on the plan mould, which is therefore made the place of the first joint. The point *c* is that point of the rail where the third riser occurs, and may with propriety be made the place of the second joint. Take the stretch-out of the exterior curve, *d* to *g*, and make the line *c g*, in No. 2, equal thereto, and set out the bottom line A B of the falling mould two inches below *c g*. On A B, set off the height of the rail at *c*, equal to two risers; draw the line *l* to the inclination of the rail, and the intermediate portion of the falling mould, as a fair curve, connecting the straight lines; make the centre and top lines of the falling mould parallel to the bottom line, to suit the depth of the rail. This completes the falling mould. For the face mould, in No. 1, draw through the centre of the joint lines the lines *c g*; make *c d* perpendicular thereto, and draw *d g*. Take the distance, *c e*, from No. 2, and set it out from *a* to *b*, No. 1, and make the point *b* in the centre of the width of the rail; this will be the seat of the intermediate height, and *c* and *g* the seats of the highest and lowest heights. Take the length of *e f*, No. 2, and apply it at *e f*, No. 1, parallel to *d c*; draw the line *e b* for the leading ordinate and square from it, as a tangent to the curve of the scroll; draw *b t*, the base line for the wreath, and draw *t s* and *g n* perpendicular to *b t*, then draw the hypothenuse, and continue the ordinates *a i k l m*, &c., to meet it. From the points of intersection draw the ordinates 1 2 3 4 5 6 7, &c., making them respectively equal to the ordinates *a a t i k b l m*, &c; and through the points thus obtained, prick off the mould.

We have thus endeavoured to give not only one general method of producing a face mould, and by one demonstration sought to make it apply to any number of cases whatever, but have also given a variety of instances of applying the same in actual practice.

We shall now proceed to describe certain details, which could not, without embarrassing the subject, be noticed before.

Sections of Handrails.—In Plate XCIV. some of the usual forms of the sections of handrails are given. To describe *Fig.* 3, divide the width 6 6 in twelve parts, bisect it by the line A B, at right angles to 6 6; make C B equal to seven, A C equal to three such parts, and B *i* also equal to three parts; set off one part from 6 to 7, draw the lines 7 *i* on each side of the figure; set the compasses in 4 4, extend them to 6 6, and describe the arcs at 6 6 to form the sides of the figure; also set the compasses in B, extending them to A, and describe the arc at A to form the top; make *l* B equal to two parts, and draw the line *k l k*; take four parts in the compasses, and from the points 4 4 describe the arcs *e f*, then with two parts in the compasses, one foot being placed in *k*, draw the intersecting arcs *g h*; from these intersections as centres, describe the remaining portions of the curves, and by joining *k i*, *k i*, complete the figure.

Fig. 5 is another similar section of handrail. The width 6 6 is divided into twelve equal parts as before; the point 4 is the centre for the side of the figure, which is described with a radius of two parts; A *m* is made equal to three parts, and B *m* to eight parts, and *m n* equal to seven parts; then will A B be the radius, and B the centre for the top of the rail. Take seven parts in the compasses, and from the centre 6 in the vertical line A B, describe the arcs *g h*, *g h*; take six parts in the compasses, and from the centre 4, describe the arcs *e f*, *e f*; draw the line *d d* through the point *n*; from the intersections at *e f g h*, as a centre, with the radius of four parts, and from 4, as a centre, with the radius of two parts, describe the curve of contrary flexure forming the side of the rail; then from *d*, with the radius of one part, describe the arc at *d*, forming the astragal for the bottom of the rail.

In *Fig.* 4 divide the width C D into twelve equal parts; make 6 *m* equal to 6 parts; 6 B and *m h* respectively, equal to two parts, and *m* 1 equal to three parts; make *e h* and *h f* respectively, equal to two parts; then in *f* and *e* set one foot of the compasses, and with a radius equal to one and a half parts, describe the arcs *g g*; from the point *m*, with the radius *m* A, describe the arc at A meeting the arcs *g g*, to form the top reed of the figure; from 2 with a radius equal to two parts, describe the side reeds C and D; draw 1 *d* parallel to A B; and with a radius of one part from the points *d d* describe the reed *d* for the bottom of the rail, which completes the figure.

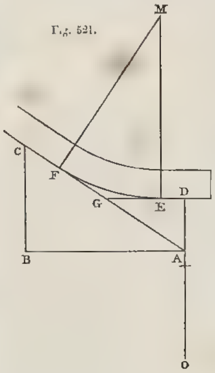
Fig. 6.—To describe this figure, let the width 6 6 be divided into 12 parts; make *m* 4 equal to four parts, *m* 6 equal to 6 parts, and 6 8 equal to 2 parts; make 6 *d* equal to 5 parts, and draw the dotted lines *d* 4; also the lines 4 *g*. On these lines make *l* 4 equal to two parts, *l o* equal to half a part, and *o g* equal to four parts; also make *m k* equal to one part, and draw the lines *g k*; from *k*, as a centre, describe the arc at A for the top of the rail; from *g* describe the arcs *h o*. At 4 and 4, with the radius of two parts, describe the arcs at 6 for the sides of the rail; then from *d* set off the distance of two parts on the line *d* 4, and from this point as a centre, with a radius of two parts, describe the curves of contrary flexure terminating in *d d*, which will complete the curved parts of the figure. Continue the line 6 6 the distance of four parts on each side to the points 4′: from these points, and through the points *d d*, draw the lines *d d* for the chamfer at the bottom of the rail, thus completing the entire figure.

To form the Section of the Mitre Cap.—*Fig.* 3, Plate LXXXIX, exhibits the method of producing the section of the mitre cap from the section of the handrail.

Let A B C D, &c., be the section of the handrail. Draw the line G G in the centre of the section, and draw across it, at right angles, the line A B; describe a circle 0, 11, *j*, *h*, having its centre on the line G G, and its diameter equal to the size of the cap. From the outsides of the rail A B, draw lines A *h*, B *j*, parallel to the line G G, and meeting the circle of the cap at *h j*. From the points of intersection *h j*, draw lines meeting on the line G G at a point *i*, as far into the mitre cap as it is proposed to carry the mitre. Then draw lines parallel to G G, through as many points in the rail as may be required, as B C D E F, continuing them till they meet the mitre lines *h i*, *j i*; set one foot of the compasses in the centre of the circle *o* 11 *j h*, and extending the other to each of the points in succession, describe circular arcs meeting the diameter 0, 11. From the points of meeting draw the ordinates, 1 2 3 4 5, &c., making them respectively equal to the corresponding ordinates, B C D E F, &c., and draw the figure through those points.

To draw the Swan-Neck at the Top of a Rail, as in Plate LXXXVIII. *Fig.* 1, No. 1.—Continue the bottom line of the rail upwards till it intersects the line of the back of the last baluster; draw a horizontal line through the top of the newel, measure from this line down the back of the baluster to the intersection, and set off the same distance downwards on the under side of the rail, from which square out a line to intersect the horizontal line above; this will give the centre point of the curve. A slight variation from this will be seen in *Fig.* 2, Plate LXXXIX., the rail being there brought nearer to the newel. This variation will be easily understood, and needs no description.

Fig. 521.



To form the Knee at the Bottom Newel.—Draw out the width of one step, as at A B (Fig. 521), and the risers connected with it above and below B C, O A, and join A C; continue the line of the first riser O A upwards to the height of half a riser at D; and through D draw a horizontal line meeting the hypothenuse A G in G. From D set off towards G, half the width of the mitre cap D E, make G F equal to G E; draw F M square from the under side of the rail, and make E M perpendicular to D G, and the point M will be the centre of the curve.

Scrolls.—Plate C.—In *Fig.* 1 is shown a very simple manner of describing a scroll. Take the width of the rail in the dividers, and repeat it three times on the line 1 2 3, which gives the first or greatest radius for the quadrant A. Refer now to *Fig.* 1, No. 2, where the scheme of centres is drawn out at full size. Draw 1 2 at right angles to the first line, and make it equal to two-thirds the width of the rail. Draw 2 3 at right angles to 1 2; make it equal to three-fourths of 1 2, and join 3 1; through 2, and at right angles to 3 1 draw the line 2 4; then draw the line

3 4 at right angles to 3 2, the line 4 5 at right angles to 3 4, or parallel to 3 2, and so on with the other lines, always squaring from the one last drawn, and thus the centres are obtained, from which the quadrants B, C, D, E, F in *Fig.* 1 are drawn.

Fig. 2, No. 1, is shown as a rail of $2\frac{3}{4}$ inches in width; the square is here made half of that width, or $1\frac{3}{8}$ inch, the first radius is made $7\frac{1}{2}$ times the square, and as the side of the square is once lost by the half revolution, the width of the scroll will be equal to 14 times the side of the square, or $19\frac{1}{4}$ inches; the construction of the square will easily be understood by a reference to *Fig.* 2, No. 2, where it is shown full size, the numbers showing the points for the centres in succession, beginning with the least radius, and ending with the greatest.

Fig. 3 is perhaps more simple than the preceding, and is adapted for a large rail, where only a small scroll can be used. The first radius is made equal to 8 inches. This distance is divided into five equal parts, and the square is made equal to one of the parts. The angles of the square are the first four centres, the middle of the side is the fifth, and the centre of the square the sixth centre.

Fig. 4 shows a ready method of producing a converging series in geometrical progression, as such a series is often found useful in setting off the radii of scrolls. The lengths of any two lines being known—to form a series from the same: take the longest line, as A B, and make it the perpendicular of a right angled triangle, the base of which B C may be made of any convenient length; let *d* be the length of the second line in the series; from A B draw the perpendicular *b d* meeting A C in *d* and join *b* C; draw the line *d e* at right angles to B C, continuing it to meet B C, draw *e f* perpendicular to A B, then draw *f g* perpendicular to B C, and *g h* perpendicular to A B; this process may be continued to any extent, and the lines A B, *d*, *f*, *h*, &c., and also *b*, *e*, *g*, &c., and *b d*, *e f*, *g h*, &c., will be a series in geometrical progression.

Fig. 6 is a method of producing a scroll by sixths of a circle. Describe a circle as A B, and divide its circumference into six equal parts, and draw the diameters shown by the darker lines on the drawing. Divide one of the divisions of the circle into six equal parts, and set off one of the divisions, equal to 10 degrees, from each diameter; then draw the second series of diameters shown by fainter lines; or the ten degrees may be set off at once by a protractor. At the distance of two inches from the centre draw the first radius *a* parallel to the faint diameter and intersecting A B; from the point of intersection draw the next radius parallel to the next faint diameter, intersecting the next succeeding darker lined diameter, and continue drawing the radii parallel with the faint-lined diameter, and their points of intersection with the first series of diameters from the centres of the curve of the scroll. The lines so drawn form a converging series, and their lengths are to each other in geometrical progression. In the figure the series is continued from *a* inwards, through one revolution and a half.

Figs. 5, 7, and 8 are methods of drawing scrolls by eighths of a circle. As they differ only in the quickness of their convergency a description of one will suffice for all.

In *Fig.* 7 proceed first to make the double cross by drawing right angles and bisecting the same, as shown on the figure. The centre of the largest arc of this scroll is situated at a distance of two inches from the centre of the scroll to the right, on the line *b*, and the next centre on the increasing side, $2\frac{1}{4}$ inches from the centre; the most ready method of producing the converging radii is by cutting a small piece of paper to the angle which the radius of the curve makes with the diameter of the scroll, and using this as a bevel to the next diameter, and so on in succession, either converging or diverging; thus the angle of radius and diameter, taken at *c*, may be applied at *b*, at *a*, and so on in succession, producing each centre by its intersection with the next diameter. The lines of the radii *c b a* are continued out in the open space of the scroll in this figure, beyond where their use occurs, that the manner of obtaining one from the other may be the better seen.

Fig. 9.—This shows a vertical scroll, sometimes used for terminating a hand-rail when space cannot be afforded for a horizontal scroll. The method of drawing it is so obvious as to need no description.

Fig. 10 is a scroll step suitable for the scroll of the rail shown at *Fig* 7. The centres of the various arcs are found as in *Fig.* 7, the same centres being used for the line of balusters and the line of nosings; then, to describe the block and step, take the length of radius of one of the arcs in the rail mould from its centre to the centre of the rail, and from its corresponding centre in the block, which will extend to the centre of the baluster, as from *c* to *e*; draw out the section of the baluster *e* to the intended size; then extend the compasses from the centre of the curve to the inside of the baluster, and describe from each centre in succession, to produce the interior curve of the block. The width of the block at its neck, that is, at *g*, should always be commensurate with the size of the baluster, as there shown; from this place the outer or convex line of the block is determined, and is struck round from the same centres as before, which are also used for the nosing line, thereby showing the size of the stepboard. At *a* is shown what is usually called the tail of the block. It is secured by a screw to the thick part of the riser. At *i* is shown the shoulder of the riser; from this point the riser is reduced to a veneer, which is carried round the convex portion of the block as far as the point *h*, where it is secured by a pair of counter-wedges, there shown in section. On the back part of the step is a line indicating the position of the second riser of the stairs, and the section of the baluster on the second step is shown; from this baluster to the next at *e*, should be equal to half the going of one step; and, in spacing the balusters round the scroll, it is desirable that their distances from each other should gradually diminish as they approach nearer to the centre of the scroll, and that the balusters of the inner revolution should be as near as possible in the centres betwixt those of the outer revolution; otherwise they will look crowded and irregular.

PART EIGHTH.

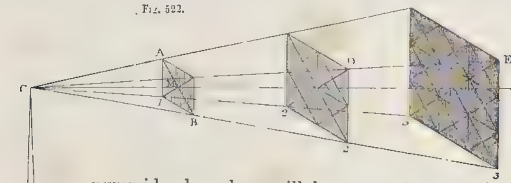
PROJECTION OF SHADOWS, PERSPECTIVE, ISOMETRICAL PROJECTION.

PROJECTION OF SHADOWS.

As a luminous point can be seen on all sides at the same instant, it follows that there must proceed from it an infinite number of rays diverging in every direction, and extending indefinitely in straight lines. The point may thus be considered as the centre of a luminous sphere, and that sphere itself may be conceived to be composed of an assemblage of pyramids or cones, whose summits are in its centre, and whose sides are indefinitely extended. Thus an eye placed at any distance from a luminous point, C, (Fig. 522), will receive a certain number of its rays, which may be considered as forming a cone, whose base is the pupil of the eye, and whose summit is the luminous point. That one of the rays which passes through the centre of the pupil of the eye, and through the point, will be the axis of the cone. If the eye, in place of being round, were square or triangular, there would be a pyramid in place of a cone of rays.

If at the distance 1, from a luminous point C, (Fig. 522), there is placed a square plane, A B, it will intercept a certain number of the rays from C. These rays will form a

Fig. 522.

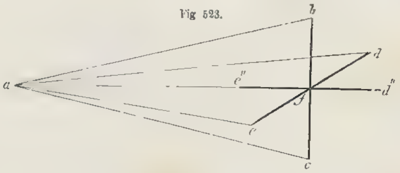


pyramid, whose base will be A B, and whose apex will be C. Conceive the sides of the pyramid prolonged indefinitely, and on its axis, C O, set off the equal lengths C M, M N, N O, or, which is the same thing, divide the axis C O into equal parts in M N O; and at each division draw a square plane perpendicular to the axis, and cutting the sides of the pyramid in 2 D, 3 E; the side of the square, 2 D, will be double the side of the square A B, and the square itself will consequently, in area, be quadruple the extent of A B. But the surface of the second square receives only the same number of rays as the surface of the first, consequently it will be only one-fourth part as light. In the same way a square at 3 will have its side three times as great as the side of the first square, and its surface thus being nine times greater will receive only a ninth part of the light. The light then evidently diminishes in respect of the distance of the illuminated object from the luminous point, in the ratio of $1, \frac{1}{4}, \frac{1}{9}, \frac{1}{16}$, for the distances, 1, 2, 3, 4; or, as it is ordinarily expressed:—*The intensity of the light is in the inverse ratio of the square of the distance.*

It also follows, by a parity of reasoning, that if it be regarded as converging towards any point, its intensity will increase in the same manner; and hence the general rule—*that the intensity of light increases or diminishes in the ratio of the square of the distance.*

Again, suppose a (Fig. 523) to be a luminous point, and b, c, a, a pyramid of rays, and let $b\,c$ be a plane cutting it perpendicularly. This plane receives the sum of the rays measured by the angle, $b\,a\,c$. Suppose the plane now turned round f as an axis into the position $d\,e$, draw the rays $d\,a$, $e\,a$, and the plane will receive now only the

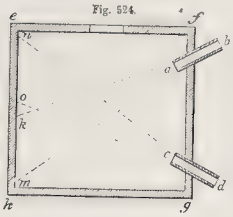
Fig 523.



sum of the rays, measured by the angle $d\,a\,e$. Conceive it further turned until it is horizontal, as $d''\,e''$, then the plane, it is evident, receives no light, and is therefore in shade. Hence the rule: when a surface receives the light perpendicular to its plane it will be lighted to its maximum intensity, and that intensity will diminish in the ratio of the obliquity of the surface to the direction of the light.

When a luminous body has extent, it is to be regarded as composed of an infinite number of light-giving points like a, sending out rays in all directions, which cross without confounding each other. The following simple experiment will prove this. Insert two tubes $a\,b$, $c\,d$, in one side of a box $e\,f\,g\,h$ (Fig. 524), and let them be in the same plane, and inclined to each other. Let there be an aperture in one side of the box so that the interior can be seen when the eye is applied to it. Then furnish one tube with a blue coloured glass, and the other with a red coloured glass. If the tube with the blue glass be stopped, and the light be admitted by the other, there will be an oval of red light thrown on the side of the box opposite to the tube at $k\,m$, and if the red glass tube be stopped, and the blue glass tube be opened, there will be an oval of blue light at $n\,o$. If both tubes be opened together, there will be an oval of red and an oval of blue, although the rays cross each other in their passage. Hence, the rays of light cross each other in every direction, without obstructing or confounding each other.

Fig. 524.

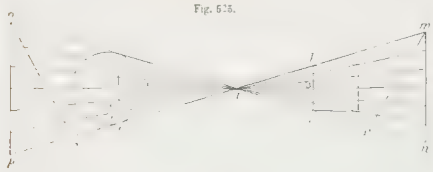


These preliminary notions of the properties of light are necessary to the proper understanding of what follows on the subject of shadows.

Let a (Fig. 525) be a luminous point from which rays diverge in every direction, and let b be an opaque body, a cube for example, and c another opaque body, say a

sphere. The parts of these bodies which receive the rays will be more or less illuminated, and the parts which do not receive the rays will be more or less deprived of light, and will be, as it is termed, in shade. Thus, the face *b d*,

Fig. 525.



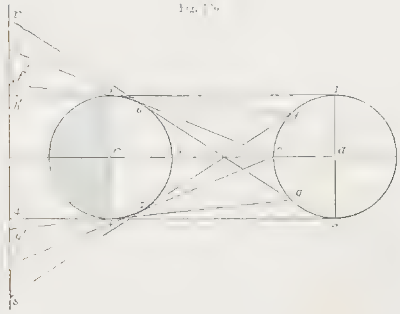
of the cube will alone be illuminated, and its other five sides will be in shade. In the same way the rays *a e*, *a f*, *a g*, &c., tangents to the sphere, determine a segment which will be illuminated, and the other segment will be in shade. But the rays which touch the boundaries of the face of the cube, if prolonged, form an indefinite pyramid, truncated by the plane *b d*, the part *a b d* will be a luminous pyramid formed by the unintercepted rays, and the indefinite portion beyond will be the shadow thrown by the opaque body. Thus, the shadow thrown by a body may be considered as a solid, the form of which is dependent on the luminous body emitting the light, the opaque body intercepting the light, and on the positions of these bodies relatively to each other. The shadow therefore thrown by the cube in the figure will be a quadrangular pyramid, and that by the sphere, a cone.

The shadow thrown by a body will appear to increase in intensity in proportion as the light which illuminates the body increases in intensity, but this is simply the effect of contrast.

If the rays of the pyramid and of the cone be cut by planes *m n*, *o p*, perpendicular to their axes, the projections will be a square and a circle. If the planes be oblique to the axes as *m r*, *o s*, the projections will be a lozenge and an ellipse.

The luminous body, in respect of that which is illuminated by it may have three different dimensions. 1st. It may be smaller, and in this case it may be compared to the light of a candle, and the portion of the opaque body illuminated will be smaller than the portion in shade 2nd. It may be of the same size, in which case the illuminated part of the body will be equal to the shaded part. But here another kind of shadow makes its appearance.

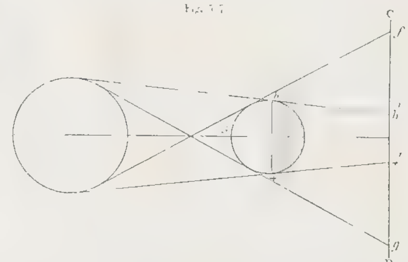
Fig. 526.



Let *a* (Fig. 526) be the luminous, and *c* the opaque body, both spheres of the same size. Now, from every point of the surface of *a* luminous rays emanate, but those alone situated on the hemisphere 1 2 3 are projected on *c*. These will be all tangents to the opaque sphere at the points *b c* 4, and will determine the extent of the illuminated segment, which will manifestly be the hemisphere *b* 5 4, and the other hemisphere will be in shade; the primary shadow thrown by the body will be a cylinder, and its intersection by the plane *r s*, perpendicular to the axis, will be a circle. But as the luminous rays emanating from *f g*, and the other infinity of points on the surface of the body *a*, are intercepted by the opaque body *b* at the tangent points 6 7, &c., the shadow of each of these points will also be thrown on the plane *r s*. Therefore, and confining the illustration for simplicity to these points in the meanwhile, it will appear that a second shadow will be thrown on the plane, considerably augmenting the size of the first. On attentive consideration, however, the two shadows will be seen to be very different, for, from the point 2 emanate rays 2 *o*, 2 *p*, which are not intercepted by the opaque body, and which, therefore, illuminate the plane within the space occupied by the secondary shadow, and which consequently diminish its intensity. This will be seen to be the case with the rays emanating from all the points of the surface of the luminous body contained between *f* and *g*, and by drawing the figure to a large scale, and projecting rays from a great number of points, it will be satisfactorily seen that the second shadow, in proportion as it extends beyond the first, will continue to decrease in intensity. The second shadow is called a penumbra.

3d. The luminous body may be greater than the body receiving light from it. In this case, as is made evident by the Fig. 527, the segment of the body illuminated,

Fig. 527.



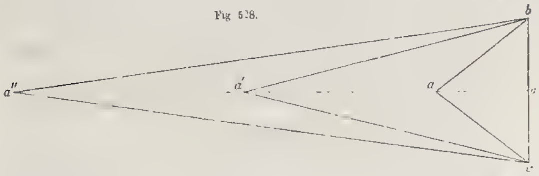
b 5 4, will be greater than the segment in shade, and the shadow *b′* 4′ thrown on the plane C D will be less than the intercepting body. The penumbra *f g* is analogous to the preceding one.

It may therefore be concluded that the shadow thrown by any body diminishes always in intensity from the first limits of the penumbra to the last; and, further, that the parts of the same surface which are nearest the luminous point will be more highly illuminated than those that are more distant.

If a luminous body at *a* (Fig. 528) illuminate a plane *b c*, the rays *a b*, *a c*, together with the plane, will make the triangle *b a c*. If it be removed to *a′ a″*, &c., the triangle becomes more and more acute, and its sides approach nearer to parallel lines, and as the lines approach parallelism, the rays emanating from *a*, and forming the pyramid, approach equality in length; and hence the plane *b c* will be more equally lighted the more distant the luminous point is from it, as if, in point of fact, the luminous body were equal to the surface illuminated. This supposition gives great simplicity in the projection of

shadows, where we suppose the light of the sun or of the moon as the illuminating medium, and from the immense distance of these bodies consider the rays as parallel; and

Fig 528.



hence, surfaces illuminated by their light are regarded as illuminated in equal intensity in all their extent.

Before entering on the consideration of the modification of shadows by reflection, and their modification also by colour, it will be necessary to carry this investigation into optics somewhat further; but in the meantime, enough has been furnished as an introduction to what follows:—

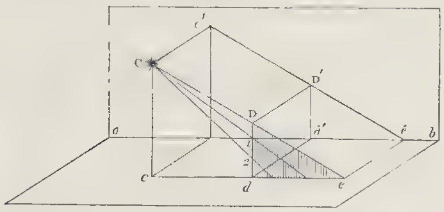
ON THE PROJECTION OF SHADOWS.

The preliminary matter has unfolded the general idea of shadows, and prepared for the consideration of the construction of shadows produced by bodies exposed to different kinds of lights.

PROBLEM I.—*The projection of a luminous point being given, and also of a straight line, to find the length and direction of the shadow of the line on the horizontal plane.*

Let *a b* (Fig. 529) be the common section of the two planes, C the luminous point, *c c′* its projections, and *d*, *d′* D′ those of the straight line. Then draw the line C D representing the ray from C, passing through D, and continue it to meet the horizontal plane in *e*. This

Fig. 529.

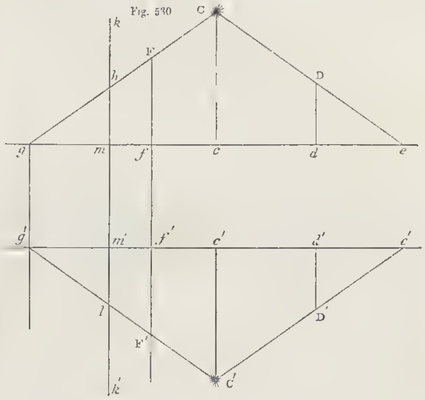


point will be the shadow of the point D. Other rays C 1, C 2, will be intercepted by D *d*, and there will be behind *d* D, therefore, the right angled triangle *d* D *e* deprived of light. This triangle may be considered as a vertical plane cutting the horizontal plane, and its intersection will therefore be the straight line *d e*. It may also be considered as the projection of the hypothenuse D *e* of the triangle *d* D *e*. Suppose the triangle prolonged indefinitely to the left, and it is evident that its plane will pass through the light C. The light, therefore, the given straight line, and the projection of the latter, are manifestly in the same plane; and since *d e* is the projection of D *e*, *c d* will be that of C D, or rather *c e* will be the projection of the ray C *e*, or of the hypothenuse of the triangle *c* C *e*. Consequently, the shadow thrown by the line *d* D will be found in the trace of a vertical plane, passing through the horizontal projections of the light, and of the given line.

Let there be given the line D *d* (Fig. 530), the height of the luminous point C *c*, and let it be required to find the shadow of the line on the horizontal plane. Through *c′* and *d′* the horizontal projections of the light and of the line, draw the indefinite line *c′ d′ e′*, which will be the trace of a vertical plane, passing through C and D; then through D, the extremity of the straight line in the vertical projection, draw an indefinite ray from C, meeting the common section of the two planes in *e*, which gives the place of the shadow of the point D. Transfer this to the trace in the horizontal plane in *e′*, and the shadow sought will be the line *d′ e′*.

Let *c′*, C′, *d′*, *d* D, be the horizontal and vertical projections of the light, and of the straight line. Through *c* and *d′* draw an indefinite straight line, which consider as

Fig. 530



the trace of the vertical plane. Suppose this plane turned over on *c′ e′* as an axis until it lies horizontally, which is done in drawing an indefinite perpendicular to the trace *c′ e′*, and carrying on it the height *c* C of the luminous point from *c′* to C′; and in the same manner drawing the perpendicular to *d′*, and setting off on it the height *d′* D′ of the straight line *d* D, and through C′ and D′, drawing a line meeting the trace in *e′*, which determines the length of the shadow *d′ e′*.

To determine the shadow of a straight line, of which a part is intercepted by a vertical plane.

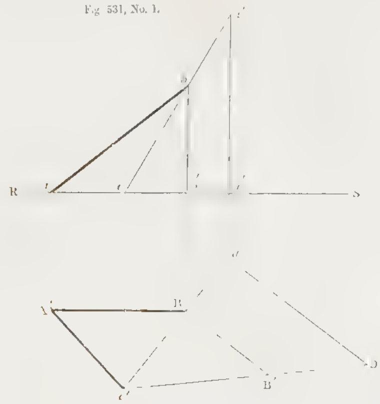
Let *f* F (Fig. 530) be the given line. Through it, and through the light C, suppose to pass a vertical plane, of which the horizontal trace is *c′ g′*, then draw the ray C F prolonged to meet the common section, and cutting it in *g*, *f g* would be the length of the shadow of *f* F if there were no obstacle. But suppose a vertical plane *m k* interposed so as to receive a portion of the shadow, and that it is required to find that portion. If, as before, the triangle C *c g* is folded down on *c′ g′* as an axis, it will produce the triangle *c′* C′ *g′* on the horizontal plane, and there will also be found the line *f* F in *f′* F′, the indefinite intersection of the plane *m k* in *m′ k′*, and it is only necessary to draw C′ F′ meeting the vertical plane in *l* and the line *m′ l* will be the shadow.

PROBLEM II.—*Given a luminous point, and a straight line inclined to the horizontal plane, to find the shadow of the line on the plane.*

Let A B, *a b* (Fig. 531, No. 1) be the projections of the line, and *d*, *d′ d″* of the point. If the former problem has been understood this will offer no difficulty. Through *b*

from d'' draw a straight line, meeting the common intersection in e; draw through e an indefinite line, perpendicular to R S, the common intersection, and through B

Fig. 531, No. 1.



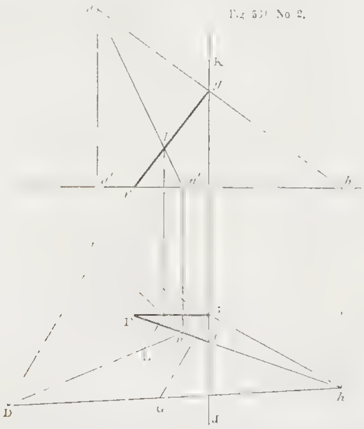
draw from the horizontal projection of the luminous point d a straight line cutting the last perpendicular in e'; join A e', which will be the shadow sought. This problem may also be solved by laying the light and the straight line in the horizontal plane, as shown in the figure. It is so simple that it requires no description.

When the shadow is in part intercepted by a vertical plane.

PROBLEM III.—*The projections of a straight line inclined to two planes being given, to find its shadow on the two planes.*

Let F G, $f\ g$ (Fig. 531, No. 2) be the projections of the line, and d, $d'\ d''$ those of the light. Now, a luminous ray passing through G will project the shadow of that point on the horizontal plane at h if no obstacle intervenes. Through F draw the straight line F h, which will be the

Fig. 531, No. 2.

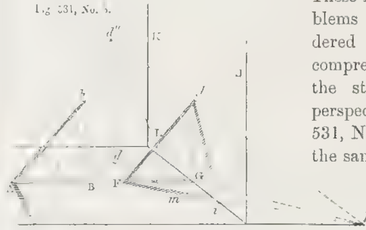


shadow of F G inclined to the horizontal plane. But there is interposed the vertical plane J K, which intercepts the ray G and its shadow in i; and as the extremity of G touches the vertical plane, the shadow of G will be at its point of contact, in the same way as the shadow of F at its touching point with the horizontal plane. Draw therefore G i, and the shadow sought will be F i, G i.

But in solving this problem there is a difficulty frequently occurring as follows:—If the extremity G, or g of the line were more elevated than in this example, the luminous ray would meet the horizontal plane at a distance too great to be within the limits of the paper, and if G were as high as the luminous point, it is evident that the ray would be parallel to the horizontal plane. In such cases take any point in the straight line F G, as l, and through it, on the horizontal projection, draw l L parallel to d D; draw through l and through d an indefinite straight line, and then through D and L draw a ray which cuts $d\ l$ in m, which is one of the points of the shadow sought. Through this point and F draw a straight line, prolonged to meet the vertical plane J K, and the point i of intersection will be obtained as in the preceding operation.

If it is required to operate by the projections of the straight line and luminous point, draw the ray $d''\ l'$ to meet the common intersection of the two planes in m'; and from m' let fall the perpendicular $m'\ m$, cutting the prolongation of $d\ l$ in m, which is the point sought.

Fig. 531, No. 3.

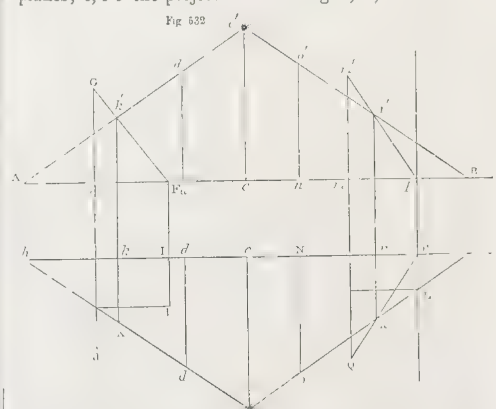


These last two problems may be rendered very easy of comprehension, by the study of the perspective diagram 531, No. 3, wherein the same letters are used to refer to the same parts.

PROBLEM IV.—*The projections of a straight line, and of a plane inclined to the planes of projection being given, to find the portion of the shadow of the line intercepted by the plane.*

Let A B (Fig. 532) be the common section of the two planes; c, $c\ c'$ the projections of the light; d, $d\ d'$ those of

Fig. 532



the straight lines; E F G those of a plane inclined to the horizontal plane. As in the former figure, it will be seen that, if no obstacle were interposed, the shadow of the line $d\ d$ would be projected on the horizontal plane in $d\ h$; that the triangle $h\ c\ c$ may be considered as an indefinite plane, cutting the plane F G in the line I J; that the inclination of that line is the same as that of the plane F G on

the horizontal plane; that the ray *c h* is intercepted by the plane F G at the point K; that this point is at the intersection of the ray, and the line I J; that this line, as well as the given right line *d d* and the luminous point, are all in the plane of the right angled triangle *h c c*, and therefore, all that is required is to turn over this triangle, and its contained lines, so that it shall lie in the horizontal plane, which is thus accomplished:—

Draw an indefinite line *c d*, which will be the trace of a vertical plane passing through the luminous point and the given straight line. Then from *c* and *d* let fall perpendiculars, and carry on them the heights *c c′*, and *d d*. From *j* draw also *j* J perpendicular to *h c*, and set off on it *j* J, equal to the height of G above *g*. From J draw J I which will be the intersection of the inclined plane. Through *c* and *d* draw the ray, cutting I J in K, which is the point sought, and from K let fall on *h c* a perpendicular K *k*, the extremity *k* of which, is the horizontal projection of K. The length of the shadow on the inclined plane will then be I K, and its horizontal projection I *k*, consequently the entire shadow will be *d* I K, or *d* F *k′*.

The problem may also be solved thus: through *c* and *d* in the vertical projection draw an indefinite straight line, and through *c′* and *d′* draw the ray, cutting F G in *k′*; from this point let fall a perpendicular on *c d* produced, and this gives, as in the former case, the point K.

In the same way the operation is performed in the case of the plane P Q or *p m′*, on the right hand, which is inclined to the straight line in the contrary way to the former.

PROBLEM V.—*Of shadows projected by rays of light which are parallel among themselves.*

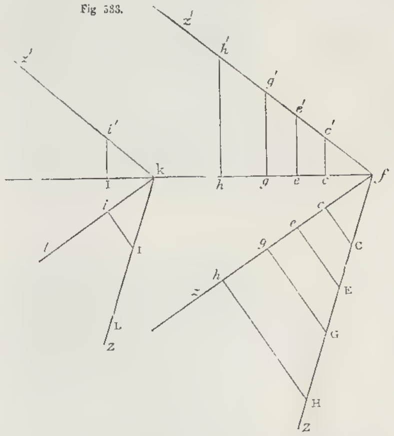
In the problems already given, the distance of the object illuminated from the light has been supposed to be known, as it is more easy thus to conceive the construction of shadow. For, if a luminous body, such as the sun, had been taken as the source of the light, it would have been impossible to have determined its place on the planes of projection relatively to the places of the bodies illuminated by it, and the question would have appeared more abstract. It is necessary now to see how, in the absence of the place of the light in the planes of projection, the shadows of bodies can be constructed.

Let *c, c c′* (Fig. 533) be the projections of a straight line, and *e, e e′* those of the light. If the light is supposed laid over on the horizontal plane its projection will be E; E *f* will be the ray, *e f* the projection of the ray, and *c f* the shadow of the given line. Conceive the ray *f* E produced indefinitely towards Z, its projection will also be indefinitely produced towards *z*. Conceive also the luminous point occupying the places successively of G and H on the prolongation of the ray, the projections of these points will necessarily be also on the prolongation of the projections of the ray in *g h, g′ h′*, &c. But it is evident that in whichever of these points, G H, the luminous point, is placed, the direction and dimensions of the shadow *c f* remain the same. Hence the actual position of the light-giving body, when its rays are parallel, is not required; it is sufficient to know the projections of a single ray.

PROBLEM VI.—*The projections of a solar ray, and of a straight line being given, to determine the shadow of the line on the horizontal plane.*

Let *z f, z′ f* (Fig. 533), be the projections of the ray, and *i*, I′ *i′* those of the line. If through *i* is drawn a line *k l* parallel to *f z*, and through *i′* another line parallel to *f z′*, these two lines will be the traces of a plane passing through the light, whatever may be its distance. These lines may be also considered as the projections of an indefinite ray,

Fig 533.

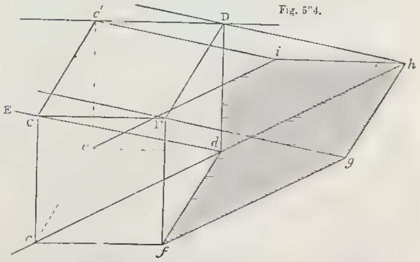


making certain angles with the planes of projections. As the right line given is equal to the right line *c* C, the shadow *i k* will be equal to the shadow *c f*. If it is required to operate directly by the ray the problem is very easy. L *k* is the direction of the ray, and the angle L *k l* is the measure of its inclination with the horizontal plane.

The projections of a solar ray then suffices to determine the shadows of different bodies. As the bodies can be illumined in an infinity of ways, the artist can choose that which is best adapted for his purpose. But architects, and engineers, and designers generally, have long agreed to adopt a certain angle, at which the luminous rays are supposed to fall upon the planes of projection, as possessing many advantages. This convention is the position that all the rays of light are such, that every one of their projections makes an angle of 45°, with the common intersection of the planes of projection, which can only have place in the case where the ray is in the direction of the diagonal of a cube, one of the faces of which is parallel to the vertical plane. The great advantage of this convention is expressed in this, that when the projections of the light make an angle of 45°, with the common section of the planes of projection, the length of the shadow of a straight line perpendicular to one of the planes is equal to the diagonal of the square of the same line. Let this be illustrated by an example.

Since the rays of the sun are parallel, and their projec-

Fig. 534.



tions also parallel, through *f d e* (Fig. 534) draw the lines

$f\,g$, $d\,h$, $e\,i$, parallel to $c\,d$, and through the points F D c' draw the rays F g, D h, c' i, parallel to E d, and their intersections will give the points of the shadow $g\ h\ i$ on the horizontal plane. Join these by the lines $f\,g$, $g\,h$, $h\,i$, parallel to c' d, F D, $c\,d$, and there is obtained the shadow of the cube on the horizontal plane.

It is very important that the ray should not be confounded with its projections, and it may be well to demonstrate this by taking the points of the cube successively. Let $c\,h$, $h\,e$, (Fig. 535) be the projections of the light, making an angle of 45° with the common section of the planes. From any point whatever, such as c, raise c C perpendicular to $c\,h$, and make it equal to $c\,c'$. Carry the height c C from c to X, and continue the line C X, which is the diagonal of the square, from c to d; draw the indefinite line C d, which will be the diagonal of the cube, or the ray sought; and the angle C d c, which is about 35° 16′, will be the measure of the ray upon the horizontal plane, and not 45°. For if the ray were inclined 45° to the plane, as C X, its length would equal the height of the right line, or the side of the square of that line, in place of its diagonal. It is important, therefore, not to confound the ray with its projections. Following out the construction of the problem, the points F D E, and their projections $g\ h\ d$, are found in the same manner as C and X.

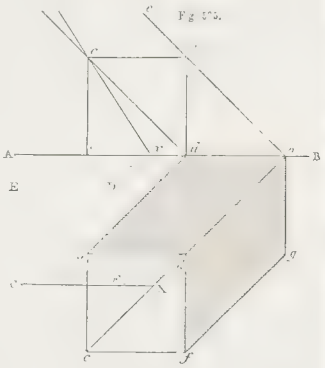


PLATE CI.—The projections of the diagonals of the imaginary cube which denote the direction of the rays of light, being equal in both planes, it follows, that in all cases and whatever be the form of the surface upon which the shadow is cast, the oblique lines joining the projections of the point which throws the shadow, and that which denotes it, are also equal. In illustration of this, let R R′ *Fig.* 1, Plate CI., be the projections of a ray of light, and A A′ those of a point, the shadow of which is required to be projected on the vertical plane X Y. Draw the straight lines A a, A′ a', parallel to R R′, and from a', where A′ a' meets X Y, the trace of the vertical plane, draw the perpendicular a' a to meet the oblique line A a, and the intersection a is the position of the shadow of the point A. It will be at once seen that the line A a in the vertical is equal to the line A′ a' in the horizontal projection, and the point a might have been obtained by the compasses, in setting off on A a a length equal to A′ a'.

PROBLEM VII.—*To find the shadow cast on a vertical wall by a straight line* A B (Pl. CI., *Fig.* 1).

As we have already seen, the shadow will be a straight line, and all that is required is to find two points in that line. The shadow of A is already found at a, and we have only to find that of B at b in the same manner, and to join a and b.

Suppose, now, that in place of a mere line we have a rectangular slip A B C D, then the shadow cast by this will be a similar and equal rectangle $a\ b\ c\ d$. Hence we have the general proposition that *when a surface is parallel to a plane, its shadow thrown upon that plane is a figure equal and similar to it.*

When the object is not parallel to the plane, the shadow is no longer an equal and similar figure, but the method of determining it is the same. In *Fig.* 2, Plate CI., let A B C D be the vertical projection, and A′ B′ the horizontal projection of the rectangular slip, and X Y the trace of the vertical plane, which is oblique to A′ B′. Draw the lines A′ a', B′ b', meeting the trace of the plane in a' and b'; draw the vertical lines a' a, b' b, meeting the oblique lines A a, C c, and B b, D d, in $a\ b\ c\ d$, and join $a\ b\ c\ d$ to form the figure of the shadow. The mode of construction is the same when the given plane remains parallel to the vertical plane of projection, and the rectangular object is oblique to it.

When there are mouldings or projections from the face of the vertical plane, the boundaries of the shadow will be an exact reproduction of the contour or section of such mouldings or projections. On the vertical plane X Y (*Fig.* 3) there is a moulding, across which the shadow of the rectangle is thrown. The fillet of the moulding is here regarded as a vertical plane in advance of X Y, and the plane of the shadow is found by drawing from its axis a line meeting A′ B′ in E′. The oblique lines drawn from E F in the vertical projection give, by their intersection with the axis of the moulding, the situation of the shadow across the fillet. The points $a\ b\ c\ d$ are found as before, and the shadow across the curved part of the moulding is a reproduction, in the horizontal projection, of its section or contour.

To find the shadow of the rectangular slip cast upon two vertical planes meeting in any angle. *Fig.* 4. Let X Y, Y Z, be the traces of the vertical planes, A′ B′ the trace of the slip, and A′ a', B′ b', the projections of the rays. From Y, the meeting of the planes, draw Y E′ parallel to A′ a, and A′ E′ will then indicate the portion of the slip whose shadow will fall on the plane X Y, and E′ B′ the portion which will fall on Y Z. The shadow in the vertical projection will consist of two parallelograms, having a common side, $e\ f$, in the intersections of the planes. The method of drawing these is obvious, and need not be described.

Figs. 5 and 6.—*To find the shadow cast by a straight line* A B *upon a curved surface, either convex or concave, whose horizontal projection is represented by the line* X e' Y.

We have already explained that the shadow of a point upon any surface whatever is found by drawing a straight line through that point, parallel to the direction of the light, and marking its intersection with the given surface. Therefore, through the projections A and A′ of one of the points in the given straight line, draw the lines A a, A′a', at an angle of 45°; and through the point a', where the latter meets the projection of the given surface, raise a perpendicular to the ground-line; its intersection with the line A a, is the position of the shadow of the first point taken; and so for all the remaining points in the line.

If it be required to delineate the entire shadow cast by a slip A B C D, as before, upon the surfaces under consideration, we shall be enabled, by the construction above explained, to trace two equal and parallel curves $a\ e\ b$,

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e f d, representing the shadows of the sides A B and C D; while those of the remaining sides will be found denoted by the vertical straight lines *a c* and *b d*, also equal and parallel to each other, and to the corresponding sides of the figure, seeing that these are themselves vertical and parallel to the given surfaces.

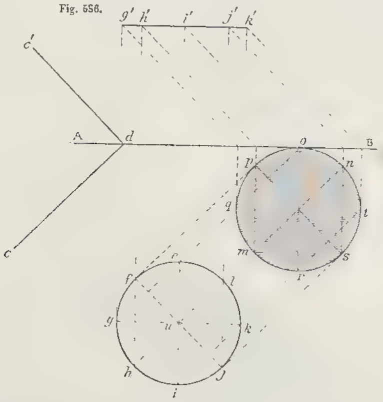
Fig. 7.—When the slip is placed perpendicularly to a given plane X-Y, on which a projecting moulding, of any form whatever, is situated, the shadow of the upper side A′ B′ which is projected vertically in A, will be simply a line A *a*, at an angle of 45°, traversing the entire surface of the moulding, and prolonged unbroken beyond it. This may easily be demonstrated by finding the position of the shadow of any number of points such as D′, taken at pleasure upon the straight line A′ B′. The shadow of the opposite side, projected in C, will follow the same rule, and be denoted by the line C *c*, parallel to the former. From this example we are led to state as a useful general rule: *that in all cases where a straight line is perpendicular to a plane of projection, it throws a shadow upon that plane, in a straight line, forming an angle of 45° with the ground-line.*

Fig. 8 represents still another example of the shadow cast by the slip in a new position; here it is supposed to be set horizontally in reference to its own surface, and perpendicularly to the given plane X Y. Here we see that the shadow commences from the side D B, which is in contact with this plane, and terminates in the horizontal line *a c*, which corresponds to the opposite side A C of the slip.

PROBLEM VIII.—*The projections of a circle and of the light being given, to find the shadow of the circle on the horizontal plane.*

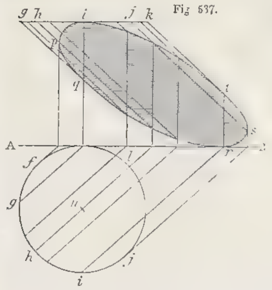
Let *c d′*, *d c′* (Fig. 536) be the projections of the light, and *e f g h i j k l* and *g′ k′* those of the circle. Take in the

Fig. 536.



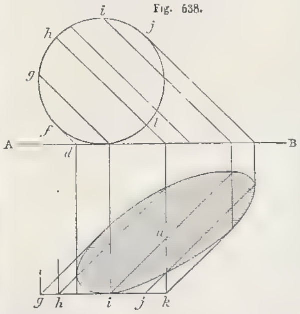
circumference of the circle as many points as may be deemed necessary, and through each of them draw right lines parallel to *c d*. These lines will be the horizontal projections of as many luminous rays. Through each corresponding point in the vertical projection, draw lines parallel to *c′ d*, which will be the vertical projections of the same rays. Through the intersections of these lines with A B, draw perpendiculars cutting the horizontal projections of the light, and each point of intersection will be the shadow of the corresponding point. Thus the shadow of *h* will be *m*, that of *l* will be *n*, and so on; and the circular shadow *n p m s*, will be the shadow of the given circle. In this simple example, the shadow being a circle, the lines given are merely for the sake of illustration. In practice it would be sufficient to find the shadow of the centre, as in the vertical projection, *Fig.* 1, Plate CII.

Fig. 537.



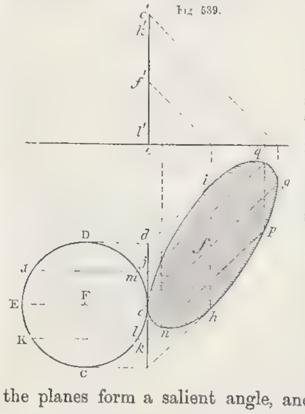
To find the shadow of the same circle on the vertical plane (Fig. 537), points are taken arbitrarily in the circumference as before, and the horizontal projections of the rays are drawn to meet A B, and from each point of intersection perpendiculars are raised cutting the vertical projections of the rays. This shadow will be an ellipse, because the cylinder of rays is cut by the vertical plane obliquely to its base.—See also illustration *Fig.* 2, Plate CII.

Fig. 538.



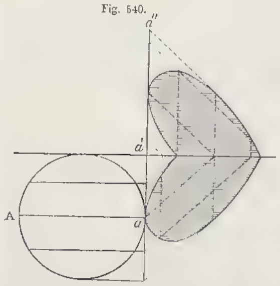
Figs. 538 and 539 present no difficulty, but will be understood by inspection. The subject is further illustrated by *Figs.* 3 and 4, Plate CII.

Fig. 539.



In Fig. 540, the shadow is thrown equally on the two planes of projection. The construction of this also will be obvious on inspection, as also that of *Fig.* 5, Plate CII., where the planes form a salient angle, and *Fig.* 6, where the shadow is thrown on a circular wall.

Fig. 540.

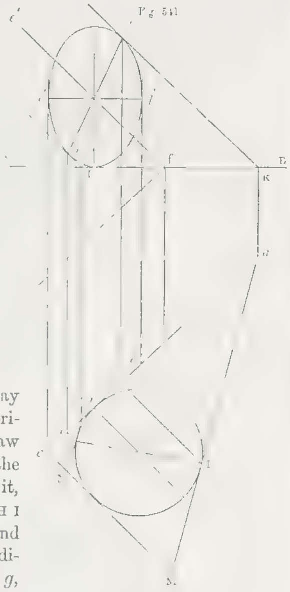


The next figure (Fig. 541) is an example of the shadow of a circle situated in the plane of the luminous rays.

Let *c d*, *c′ d′* be the projection of the circle, and *e* f, f *e′* those of the light. Through *c d* draw the indefinite line *c g*, which will be the trace of a plane passing through

the ray. To the ellipse, which is the vertical projection of the circle, draw two tangents parallel to e' f. and produce them to A B; from J k, the points of their intersection with A B, draw perpendiculars, cutting $c\ g$ in $l\ g$. These points determine the length $l\ g$ of the shadow sought. But as in what follows it is necessary to determine exactly the tangent points $h'\ i'$, they are found thus on the shadow. Lay the circle on the horizontal plane, and draw in the direction of the ray the tangents to it, M g N l, which give H I the points sought; and by letting fall perpendiculars from these on $c\ g$, their horizontal projections $h\ i$, and consequently the projections of $h'\ i'$, are exactly determined.

Fig. 541.

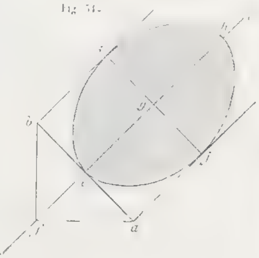


It is proper to remark, that by this second operation the shadow $l\ g$ might have been easily found without employing the vertical projection of the circle, and this knowledge affords a ready means of solving the next problem.

PROBLEM IX.—*To find the shadow of a circle whose horizontal projection* $a\ b$ (Fig. 542) *is perpendicular to the trace* $c\ d$ *of a plane passing through the ray.*

It has been seen that when the ray is in the direction of the diagonal of a cube, the length of the shadow on the horizontal plane of a right line is equal to the diagonal of the square of its height. Take therefore $e\ a$ or $e\ b$, which carry upon any perpendicular whatever, as e to f; and then take $f\ a$ or $f\ b$ and carry it from e to g and g to h, and $e\ h$ will then be the length of the shadow of the vertical diameter of the circle; then through g draw $j\ i$ perpendicular to $e\ h$, and make $g\ j$, $g\ i$, each equal to the radius of the circle, and the ellipse $e\ j\ h\ i$ will be the shadow required.

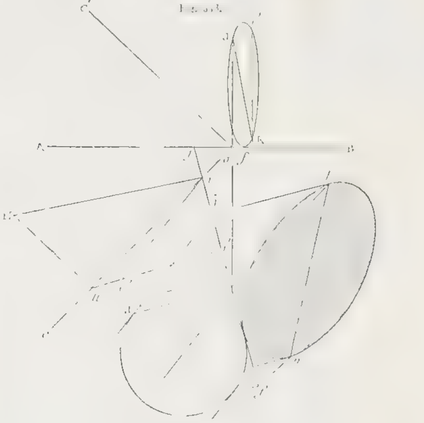
Fig. 542.



PROBLEM X.—*To find on the circumference of a circle the tangent points of planes passing through the light when the circle is not on the plane of the light.*

Let $c\ d'$, $d\ c'$ (Fig. 543) be the projections of the light, $e\ f$, $e'\ f'$ those of the circle, and let the shadow of the circle be found by the means already known. Produce indefinitely the plane $e\ f$ of the circle towards g, and consider $f\ g$ as the common section of the plane of projection. In $c\ d$ take any point whatever, as h, and from it raise a perpendicular h H; and having determined the ray H i, the right angled triangle $i\ h$ H is obtained, and its horizontal projection is $i\ h$. Find on the line $f\ g$ the projection of this triangle, which is done by letting fall upon that line perpendiculars from $h'\ i$. It is evident that the point i will be its own projection, and the projection of h' will be h; $h'\ i$ then will be the horizontal projection of the triangle $i\ h$ H. The original point of which h' is the projection, will be elevated above the horizontal plane by the height h H. Consequently this height will have to be carried from h' to H$'$, and the hypothenuse H$'\ i$ drawn, which will be the ray H i brought back to the plane of the circle $f\ g$; for the triangle $i\ h$ H being conceived to be raised on its base, $h'\ i$ will be absolutely in the plane $f\ g$, which is that of the circle.

Fig. 543.



There remains, therefore, only to draw to the circle two tangents parallel to H$'$, which give J K, the points sought, the projections of which will be j k, and their shadow on the circumference of the ellipse will be l and m.

PROBLEM XI.—*The projections of the light and those of a cylinder being given, to find the shadow of the cylinder.*

This operation is reduced to finding the shadow of the centre o of the circular top of the cylinder, which will be o'' (Fig. 544). From this point with the radius $o''\ g$ describe the circle $g\ k\ h$, and draw to it the tangents $f\ g\ e\ h$, and the shadow is determined.

Fig. 544.

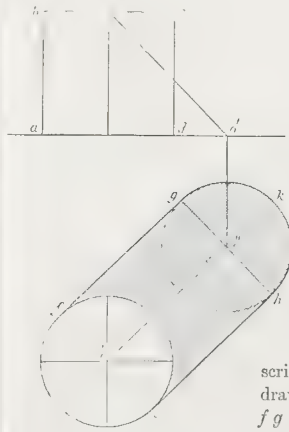


Fig. 545 represents a cylinder, the position of which is analogous to that of the circle in Fig. 537, and the construction is the same.

Fig. 546.—This is analogous to Fig. 538, and is con-

structed in the same manner. The tangent J′ Z′ should be considered as the trace of a plane perpendicular to the vertical plane, passing through that luminous ray which is a tangent to the cylinder in the line J *j*. The learner should repeat this projection with the cylinder removed further from the vertical plane, as in *Fig.* 2, Plate CIII.

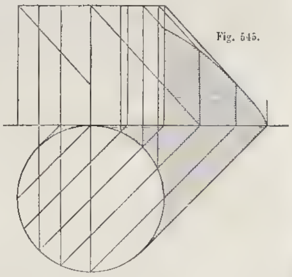


Fig. 545.

Fig. 547.—In this figure we require to find the projections of the shadows of the two bases of a cylinder, in the same manner as the shadow of the circle is found in Fig. 539. These formed, we draw tangents to the ellipses, and we shall have the shadow of the cylinder on the horizontal plane. But it is necessary, moreover, to find the tangent lines of the planes of the light, as has been done in Fig. 543, and which we shall here repeat.

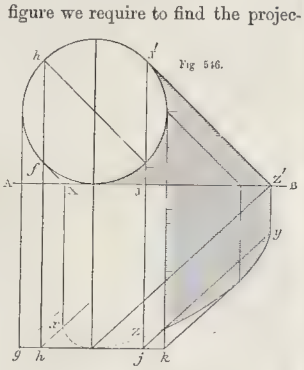


Fig 546.

Through any point *a*, taken at pleasure in the projection of the direction of the light, draw a perpendicular,

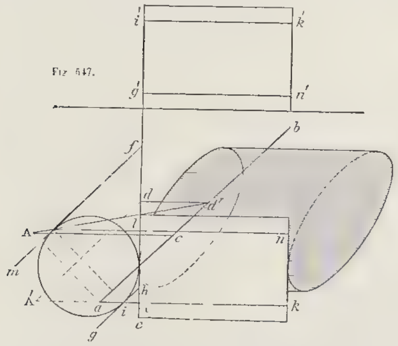
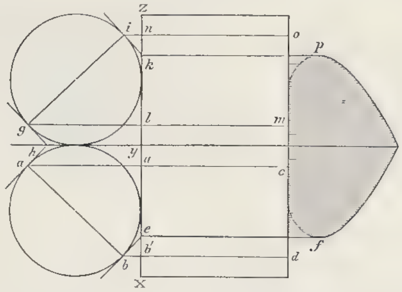


Fig. 547.

upon which take again any point A; take the height *a* A, and set it from *a* to *c*; draw the line A *c*, the diagonal of the square, and carry it upon *a b* from *a* to *d′*; then draw A *d′*, which will be the diagonal of the cube, the ray, or the hypothenuse of the right-angled triangle A *a d′*; project this triangle on *e f*, the plane of the circle produced, by letting fall on *e f* from the points *a d* the perpendiculars *a* a, *d d′*, and the line a *d* will be the projection of *a d′*, the base of the triangle. Carry the height *a* A from a to A′, and draw A′ *d*, which will be the projection sought of the ray brought into the plane of the circle. Draw parallel to this ray the tangents m *f*, *g* h, and there will be obtained the tangent points sought. From these points let fall on the horizontal projection of the cylinder the lines *i k*, *l n*, which will be the tangent lines or limits of the shadow of the cylinder above and below. Lastly, carry the heights *i* A, *l* g, on the vertical projection, and we obtain *i k′ g′ n′*, as the limits of the shadow before and behind in the vertical projection.

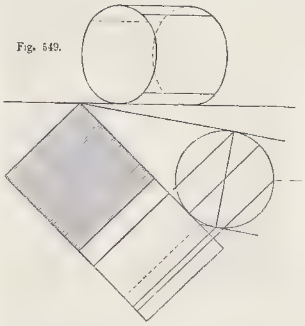
Fig. 548.—When we have made the two portions of the ellipses, as in Fig. 540, let us lay down the circle *x y* in the horizontal plane. Then project the ray in the plane of the circle, and draw tangents parallel to the ray. From *a* and *b* draw the lines *a c*, *b d*, which are the limits of the shadows, and from *e* the extremity of the tan-

Fig. 548.



gent *b e* draw the line *e f* tangent to the ellipse, and this line will be the shadow carried from the tangent line of the cylinder to the horizontal plane. Lastly, lay the circle *y z* in the vertical plane, and it will be in the same plane as the vertical projection of the light; draw to it two tangents *g h*, *i k* parallel to the projection of the ray. From *g* and *i* draw the lines *l m*, *n o*, which are the limits of the shadow on the vertical projection. From *k* draw *k p*, and this line is the shadow carried on the vertical plane by the tangent *n o*; and thus the whole shadow of the cylinder is found in the two planes.

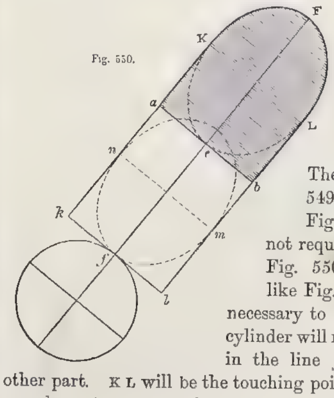
Fig. 549.



The next figure, No. 549, is analogous to Fig. 541, and does not require description.

Fig. 550 is constructed like Fig. 542. It is only necessary to observe that the cylinder will receive more light in the line *f e* than on any other part. K L will be the touching points of the luminous planes tangents to the surface of the cylinder, and the

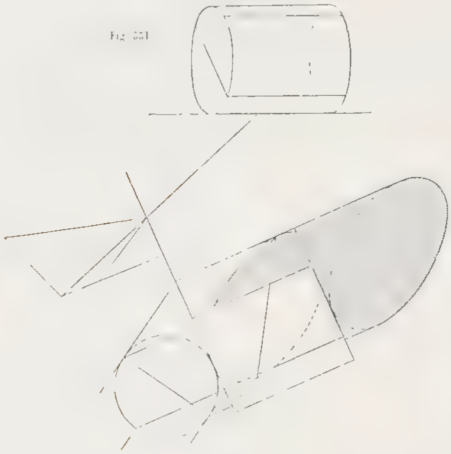
Fig. 550.



projections of these lines will be $k\ a$, $l\ b$ in the horizontal plane. The shadows of these lines in the horizontal planes will be m L n K.

Fig. 551 is the application to a cylinder of the principle of construction exemplified in Fig. 543.

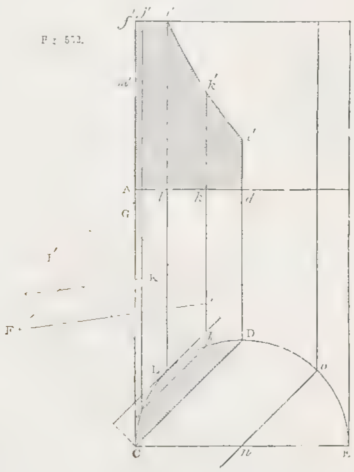
Fig. 551.



Problem XII.—*To find the shadow of the interior of a concave cylindrical surface.*

Let C D E, $c\ h$ (Fig. 552) be the projections of a concave semicylinder. Through C draw the horizontal projection of the light, cutting the curve in D; from this point raise an indefinite perpendicular D d. Through f', the vertical

Fig. 552.

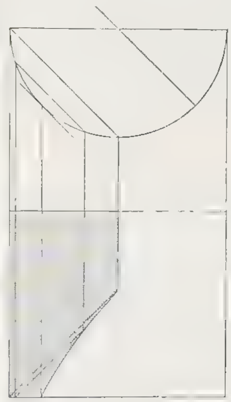


projection of the higher point of the cylinder (raised vertically over C), draw the vertical projection of the light, which will cut the line raised on the point D in i'. This point of intersection will be the shadow of f' in the interior of the cylinder.

To obtain a second point of the shadow. Through any part of the curve, as J, draw a line parallel to C D, cutting the curve in the point k; from this point raise a perpendicular, and from j', the vertical projection of J, draw a line parallel to $f'\ i'$, cutting the perpendicular in the point K, which will be the shadow of j'. Lastly, draw the horizontal projection of the light in such manner as that it may be a tangent to the curve at L. The vertical projection of this point will be l', and it will be the commencement of the shadow in the cylindrical cavity. Through these points (or any number similarly obtained) draw a curve $l'\ k'\ i'$, which will be the shadow of the circular part L, C. Then draw the straight line $i'\ d$, which will be the shadow of $f'\ m'$, a portion of the line f' A, and the shadow of the other portion m' A will be in C D in the horizontal projection.

To find this shadow directly from the luminous rays.

Fig. 553.

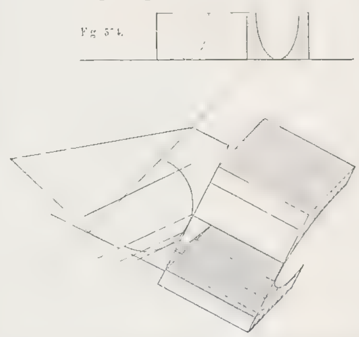


If we consider C D in the horizontal projection as the trace of a plane cutting the cylinder, the resulting section will be the rectangle D F. Draw through F a ray cutting D G in i, and the point of intersection will be the shadow of F. Carry the height D i from d to i' in the vertical projection, and we have the point sought. Repeat this for the section J k, and we shall obtain the point K, and the height k K will be equal to $k\ k'$; the tangent point L will give as its section only the line L L$'$, and consequently the point L will be itself the point in the shadow.

Fig. 553.—This is the reverse of Fig. 552, and presents no difficulty.

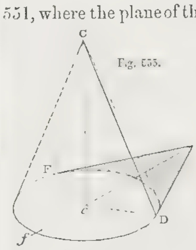
Fig. 554.—The principles illustrated in Figs. 543 and

Fig. 554.



551, where the plane of the curve is not in the same direction as the plane of the light, are applied in the solution of this problem. With these in view, the solution of this is not difficult.

Fig. 555.



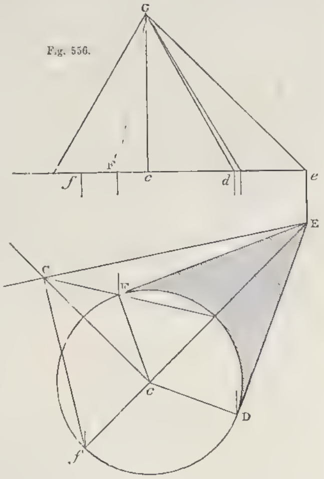
Figs. 555, 556.—Problem XIII.—*To find the shadow of a cone on the horizontal plane.*

We have already seen that the shadow on the surface of a cylinder, and also the shadow thrown by a cylinder on the horizontal plane, are determined by the line wherein a plane tangent to the surface

of the cylinder touches that surface. It is the same in regard to the cone.

Suppose the problem solved as in Fig. 555. Conceive two planes C D E, C F E, passing through the light through the limits of the projected shadow, and by the shadow of the cone, these planes will be tangents to the surface of the cone, and consequently also to the circle of its base, according to the lines D C, F C, and the line of their intersection, or the axis C E, will be in the direction of a luminous ray passing through the summit C, and projecting the shadow of that point on the horizontal plane in E. The projections of these planes will evidently be the triangles *c* D E, *c* F E.

Fig. 556.

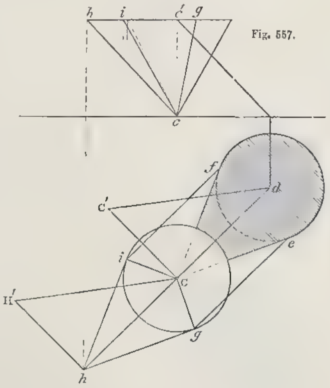


Hence, to solve this problem, it is sufficient that we have the shadow of the summit (Fig. 556), or the point E, which we can obtain by the ray C E, or by the vertical projection C′ *e*. From this point we draw tangents to the circle of the base E D, E F, and the radii D *c* F *c*, which will be the limits of the shadow on the surface of the cone, and the tangents will be the limits of the shadow thrown on the horizontal plane.

Suppose the cone placed on its summit. The projection of the shadow in this case is very easy, if we are content with a mere mechanical solution.

First find *d* (Fig. 557), the shadow of the centre C of the base. From *d* as a centre, with a radius equal to the radius of the base, describe a circle; and from the summit C draw the tangents C *e*, C *f*, and the shadow projected on the horizontal plane will be determined.

Fig. 557.



To find the boundaries between light and shade on the surface of the cone—

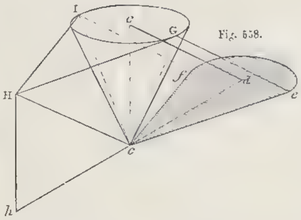
1*st.* Draw through the tangent point *e* a line parallel to C *d*, cutting the circumference of the base in *g*, and from *g* draw *g* C, and we obtain the horizontal projection of the tangent sought.

2*d.* From the centre C raise a perpendicular upon C *e*, and the radius C *g* will be the line sought.

3*d.* On *d* C produced, take the point *h*, distant from the centre by a space equal to C *d*; from *h* draw to the base of the cone the tangents *h g*, *h i*, which will give us the points *g i*.

If two planes *e* H, *f* H (Fig. 558), be conceived to pass through the rectilineal boundaries of the projected shadows, they will be tangents to the cone in the lines *c* G, *c* I, and will cut each other in the line *c* H. This line of intersection makes with the horizontal plane an angle H *c h* equal to that made by the luminous rays; consequently, the point *h* being the projection of H (which is raised above the horizontal plane by the height *c c*) will be distant from *c* the extent *c d*; for a ray passing through *c*, and projecting a shadow from that point on the horizontal plane, will be equal and parallel to H *c*.

Fig. 558.

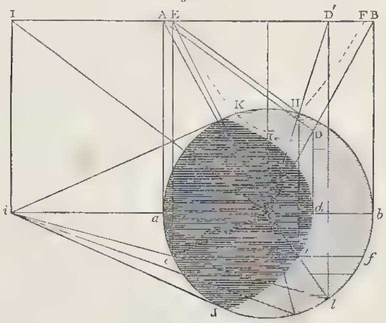


PROBLEM XIV.—*To draw the shadow on the concave interior of a cone.*

Conceive a vertical plane passing through the horizontal projection of the light, and cutting the cone (Fig. 559). Turn down this section on the horizontal plane, and we have the triangle A C B. To find now the shadow of the point *a*: through A, its vertical projection, draw a ray which will project the shadow of the point in D on the side B C of the triangle A B C. This side has for its horizontal projection the line C *b*, and as all the points in B C correspond to those in C *b*, we have only to let fall a perpendicular from D on *b* C to give us *d* for the point sought as the shadow of *a*. Take any other point, *e*, and suppose a vertical plane passing through it parallel to the first; it is evident that the shadow of *e* will be found in *e f*, and so on, and the result of the operation will be a hyperbola. This method of finding the shadow, point by point, however, is very tedious, and we shall therefore describe a more ready solution.

Produce the plane A B indefinitely towards I; through the summit C draw the radius C I; from I let fall upon the

Fig. 559.



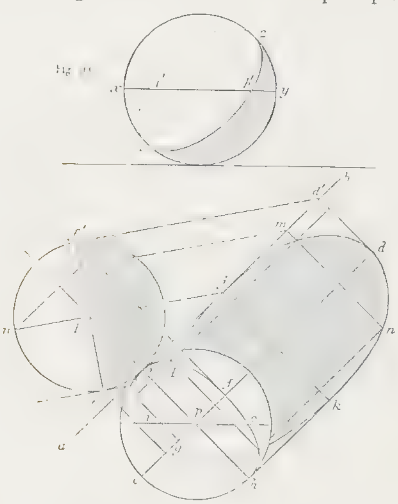
prolongation of *a b* a perpendicular, which will give the point *i*; from that point draw the tangents *i* J, *i* K, and the points J K will be the commencement of the shadow projected on the interior of the cone by the arc J *a* K; and J, K, and *d* will be three points in the shadow sought. Take another point, as *e*: then through *i* and the given

point e draw $i\ e\ l$, which will be the trace of a plane which we suppose to pass through the summit C. Now, every section of a cone by a plane passing through its summit is a triangle; draw, therefore, l C, e C, and we have the triangle E C D′, as the vertical projection of this section. Draw now through E a ray carrying this point to H on the side D′ C of the triangle, and this gives us h on the horizontal projection l C.

From this last operation is deduced a short method of finding the point. The point h is situated at the intersection of l C and $e\ f$, which contain or form the hyperbola. Through the given point e draw $e\ f$ parallel to $a\ b$, and the point sought will be found on that line. Through i and through e draw $i\ e\ l$, from l draw l C, and the point sought is also to be found in that line, and must necessarily be at h its intersection with $e\ f$.

PROBLEM XV.—*To determine the boundaries of the shadow on the surface of a sphere, and the projection of the shadow from the sphere on the horizontal plane.*

Consider the line $c\ d$ (Fig. 560), the horizontal projection of the light, as the trace of a vertical plane passing



through the centre of the sphere. The resulting section will be a great circle, which suppose turned over on to the horizontal plane, or, to avoid confusion of lines, projected vertically on the line $a\ b$. Consider this line $a\ b$ to be the common section of the planes of projection, and project on it also the luminous ray at the angle of the diagonal of a cube. This done, draw rays tangentially to the circle, and from the points $e'\ f'$ let fall on $c\ d$ the perpendiculars $e'\ e$, $f'\ f$, and the new points $e\ f$ will be the projections of $e'\ f'$. The shadow of e' will be projected on $a\ b$ in g', and that of f in d', consequently the length of the shadow projected by the great circle $e'\ n'\ f'$ of the sphere will be $g'\ d'$ on $a\ b$, or $g\ d$ on $c\ d$.

Now consider this vertical circle as a sphere, and it is evident the line $e'\ f'$ will be the boundary between the light and dark portions, as well as the vertical projection of a great circle inclined to the horizontal plane. The point p', the extremity of a horizontal diameter, as well as its opposite or antipodes, will have its horizontal projection in $h\ i$, and the line $h\ i$ will be the horizontal projection of the diameter of which p' is one extremity. The rays which pass through p' and its opposite project the shadows of these points in j, the middle of $g'\ d'$; and the horizontal projection of the shadows of these points will be $j\ k$, and we thus have—1st, the two axes, $e\ f$, $h\ i$, of an ellipse, which will be the horizontal projection of the inclined circle (of which $e'\ p'\ f$ is the vertical projection), and therefore the horizontal projection of the boundaries of the light and shade on the surface of the sphere; 2d, the two axes, $g\ d$, $j\ k$, of another ellipse, which will be the section of the cylinder formed by the rays which are tangents to the surface of the sphere by the horizontal plane, and therefore the boundaries of the shadow thrown by the sphere on the horizontal plane. These ellipses may be then traced by the aid of a slip of paper, as described *ante*, p. 24, Fig. 163; or they may be traced by finding the horizontal projection of the section of the sphere on the line $n'\ p'\ o'$, and thus obtaining points in its circumference, as at q, n.

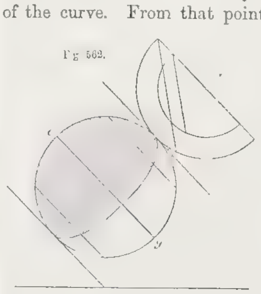
PROBLEM XVI.—*To find the shadow in the concave interior of a hemisphere.*

Find the tangent points D B (Fig. 561), and through

the centre draw the line A O C. This line will be the horizontal projection of the light, and the tangent points D B will be the commencement of the shadow sought.

To find another point in the shadow on the line A C, conceive, as in the preceding case, the hemisphere to be cut by a vertical plane, whose trace is the line A C. Turn down this section on the horizontal plane in A′ D C′. Through A′, the vertical projection of A, draw a ray, which will give the shadow of that point in a' in the concavity of the curve. From that point let fall a perpendicular upon A C, which will cut the line in a, the point sought. We have now three points in the shadow sought. To find others, take any point on the arc B A D, as E, draw through E the horizontal projection of a ray, which will cut the hemisphere in E F, and the vertical projection of that section will be the semicircle E′ F′; draw through E′ a ray carrying the shadow of that point on the curve, and let fall from the intersection a perpendicular on E F: and e is the point

Fig. 562.



sought. Proceed in the same manner to obtain other points, and draw through them the curve D e a B, the boundary of the shadow.

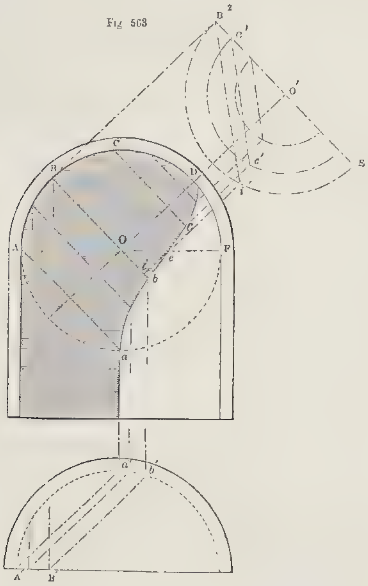
If the hemisphere is in the vertical projection, as in Fig. 562, we take $e\ g$, the vertical projection of the light, for the section plane, and proceed precisely as in the foregoing case.

PROBLEM XVII.—*To determine the shadow in a niche.*

The inferior part of the niche being cylindrical and its superior part spherical, we have to solve this problem by the combination of methods we have just learned.

Through A and A′ (Fig. 563), draw the projections of the light, and at the extremity of A′ a', raise a perpendicular, which gives the point a. The line $a'\ a$ will be the boundary of the shadow in the cylindrical part. Through O, the centre of the spherical portion, draw B b, the vertical projection of the light, cutting the hemisphere, of which

Fig. 563



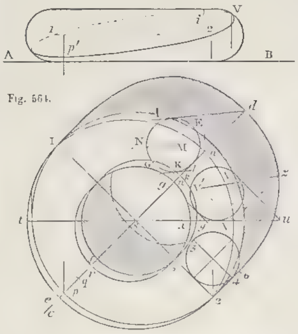
project the section in B² i' E. Draw the ray B² i', and let fall a perpendicular on B b, and the intersection i will be the shadow of B in the interior of the hemisphere. (The niche is in fact only a quarter of a sphere, but for the purpose of the problem we regard it as a hemisphere.) We have then the two semi-axes of an ellipse B O, i O, consequently we can construct the quadrant D e i of that ellipse.

Find now the horizontal projection of B in B′, and draw through it the plane B′ b'. Through b' draw a perpendicular, cutting B i in b, the point sought, and we can, by drawing the curve $e\ b\ a$, complete the boundary of the shadow. If the drawing is large, it is necessary to find more points, as shown by the dotted lines.

PROBLEM XVIII.—*To determine the shadows of a cylinder of which the axis is circular (such as a ring) and the exterior form of which is a torus.*

Let $c\ d$ be the horizontal projection of the light. The result of the section by a plane on this line will be two equal circles, having for their diameters $e\ f$, $g\ h$; and, as these circles are in the same condition as respects the light, the results will be equal; hence we require only to operate for one of them. Let this be $g\ h$, and all the points we find for this car be transferred to $e\ f$ Lay this circle in the horizontal plane in G E, and draw the rays I d, K l tangents to the circle at I and K. These points are the boundaries between the light and shade of the circle, and the shadows of these points on the horizontal plane will be at the intersections of the rays with the line $c\ d$ at the points d and l; and if we let fall on $c\ d$ perpendiculars from the points I K, we shall have their horizontal projections in $i\ k$, i being on the upper and k on the lower side. If we now draw a ray to M, the centre of the circle, we shall have N as the point most highly illuminated, and n for its horizontal projection. By these operations we have obtained the points n, k, l, i, d, which we transfer upon $c\ d$ in o, p, q, r, s. If we now make a section on $t\ u$ parallel to the common section A B, we have two circles equal to the preceding, and the projection of the light on this plane will be the same as in the vertical plane; that is, the line V u will make an angle of 45° with $t\ u$. Consequently, the tangent points will have $v\ x$ as their horizontal projections, and $y\ u$ as their shadows projected on the horizontal plane. These two points are not in their place, and, as we require only the one point u, we may, if we think fit, reject y. Through V, the horizontal projection of V, draw an indefinite line parallel to $c\ d$; the shadow of V will be found in that line at z, as follows:—1st, by raising from u a perpendicular, cutting the line in z. 2d, in carrying from v to z the diagonal of the square of the height V V. 3d, in raising from V the line V′ V′ equal to V V and perpendicular to V z, then drawing through V′ a ray, V′ z, parallel to I d, since $v\ z$ is parallel to $c\ d$.

Fig. 564.



Make still another section by the line 1 2, and the projection of the light on this plane will be an angle of 90°; the tangent points will consequently be at 3 and 4, and their horizontal projections in 5 and 2. The shadow thrown on the horizontal plane by the point 4 will be 6. We shall find this point by carrying from 2 to 6 the diagonal of the square of the height 2 4. We have now a sufficient number of points for tracing the curve i V 2, the quarter of the shadow of the body, and the curve $d\ z$ 6 2, the quarter of the projected shadow. The other portions can be found from this.

PROBLEM XIX.—*To find the outline of the shadow cast upon both planes of projection by a regular hexagonal pyramid.* PLATE CIII., *Fig.* 1.

In this figure it is at once obvious that the three sides A′ B′ F′, A′ B′ C′, and A′ C′ D′ alone receive the light; consequently the edges A′ F′ and A′ D′ are the lines of shade. To solve this problem, then, we have only to determine the shadow cast by these two lines, which is accomplished by drawing, from the projections of the vertex of the

pyramid, the lines A b and A′ a', parallel to the ray of light; then raising from the point b a perpendicular to the ground line, which gives at a' the shadow of the vertex on the horizontal plane, and finally by joining this last point a' with the points D′ and F′; the lines D a' and F a' are the outlines of the required shadow on the horizontal plane. But as the pyramid happens to be situated sufficiently near the vertical plane to throw a portion of its shadow, towards the vertex, upon it, this portion may be found by raising from the point c where the line A′ a' cuts the ground line, a perpendicular c a, intersecting the line A b in a; the lines a d and a e, joining this point with those where the horizontal part of the shadow meets the ground line, will be its outline upon the vertical plane.

PROBLEM XX.—*To find the shadow cast by a hexagonal prism upon both planes of projection. Fig.* 4, Plate CIII.

The shadows cast upon the two planes of projection are delineated in the figures, and the lines of construction which are also given are sufficient to indicate the mode of operation without the help of further explanations.

PROBLEM XXI.—*Required to determine the limit of shade in a cylinder, and likewise its shadow cast upon the two planes of projection. Fig.* 2, Plate CIII.

When the cylinder is placed vertically, the lines of shade are at once found by drawing two tangents to its base, parallel to the ray of light; and projecting, through the points of contact, lines parallel to the axis of the cylinder.

Draw the tangents D′ d' and C′ c', parallel to the ray F′; these are the outlines of the shadow cast upon the horizontal plane. Through the point of contact C draw the vertical line C E; this line denotes the line of shade upon the surface of the cylinder. It is obviously unnecessary to draw the perpendicular from the opposite point D′; because it is altogether concealed in the vertical elevation of the solid. In order to ascertain the points C′ and D′ with greater accuracy, it is proper to draw, through the centre O′, a diameter perpendicular to the ray of light F′.

Had this cylinder been placed at a somewhat greater distance from the vertical plane of projection, its shadow would have been entirely cast upon the horizontal plane, in which case it would have terminated in a semicircle drawn from the centre o', with a radius equal to that of the base. But, as in our example, a portion of the shadow of the upper part is thrown upon the vertical plane, its outline will be defined by an ellipse drawn in the manner indicated in *Fig.* 2 of the preceding Plate.

Fig. 5.—When the cylinder is placed horizontally, and at the same time at an angle with the vertical plane, the construction is the same as that explained above; namely, lines are to be drawn parallel to the ray of light, and touching the opposite points of either base of the cylinder; and, through the points of contact A and C, the horizontal lines A B and C D are to be drawn, denoting the limits of the shade on the figure. The latter of these lines only is visible in the elevation; while, on the other hand, the former, A B alone, is seen in the plan, where it may be found by drawing a perpendicular from A meeting the base F′ G′ in A′. The line A′ E′ drawn parallel to the axis of the cylinder is the line of shade required.

The example here given presents the particular case in which the base of the cylinder is parallel to the direction of the rays of light in the horizontal projection. This case admits of a simpler solution than the preceding, in which the necessity for drawing the vertical projection of the figure is dispensed with. All that is required in order to determine the line A′ E′ is to ascertain the angle which the ray of light makes with the projection of the figure. Draw a tangent to the circle F′ A^2 G′ (which represents the base of the cylinder laid down on the horizontal plane), in such a manner as to make with F′ G′ an angle of 35° 16′, and through the point of contact A^2 draw a line parallel to the axis of the cylinder; this line E′ A′ will be the line of shade as before.

PROBLEM XXII.—*To find the line of shade in a cone, and its shadow cast upon the two planes of projection. Fig.* 3, Plate CIII.

By a construction similar to that of *Fig.* 1, we find the point a'; from this point draw tangents to the opposite sides of the base; these two lines will denote the outlines of the shadow cast upon the horizontal plane. Their points of contact B′ and C′, joined to the centre A′, will give the lines A′ B′ and A′ C′ for the required lines of shade in the plan; of these, the first only will be visible at A B in the elevation.

If the cone be situated in the reverse position, as in *Fig.* 6, the shade is determined in the following manner:—From the centre A′ of the base, draw a line parallel to the light; from the point a', where it intersects the perpendicular, describe a circle equal to the base, and from the point A′ draw the lines A′ b' and A′ c', touching this circle; these are the outlines of the shadow cast upon the horizontal plane. Then, from the centre A′, draw the radii A′ B′ and A′ C′, parallel to a' b' and a' c'; these radii are the horizontal projections of the lines of shade, the former of which, transferred to B D, is alone visible in the elevation. But in order to trace the outline of that portion of the shadow which is thrown upon the vertical plane, it is necessary to project the point C′ to C, from which, by a construction which will be manifest from inspection of the figures, we derive the point c, and the line c d as part of the cast shadow of the line C′ A′. The rest of the outline of the vertical portion of the cast shadow, is derived from the circumference of the base, as in *Fig.* 2.

PROBLEM XXIII.—*The projections of a cone and a sphere being given, to determine the shadow thrown by the first body on the second.*

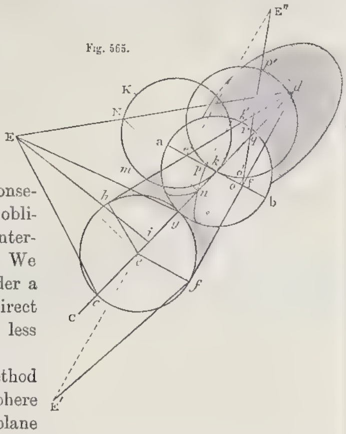
Suppose, in the first instance, that the shadows belonging to both bodies have been found.

1st. Let c d (Fig. 565), be the horizontal projection of the light; E d the ray; e E the height of the cone; f d h the shadow thrown by the cone on the horizontal plane; (the horizontal projection of the sphere being supposed removed); e f, e h the boundaries of shade on the surface of the cone; i E the vertical projection of the shadow of the cone or of the lines e f, e h; c E g the vertical projection of the cone.

The lines f d, h d are the traces of two planes inclined to the horizontal plane, tangents to the surface of the cone in the lines e f, e h, and intersecting each other in the arris E d or its horizontal projection e d. Suppose now the sphere by which portion of the shadow is to be intercepted, cut by the vertical plane c d in the diameter

$g\ q$; make the vertical projection of this section, and we have the circle K $m\ k$, which will intercept the ray E d in the point N, which has n as its horizontal projection. This point then is the projection of the shadow of the summit of the cone upon the sphere. We could in the same manner obtain other points, but this method is operose, and wants precision, in consequence of the obliquity of the intersecting lines. We proceed to consider a method more direct and involving less labour.

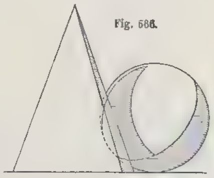
Fig. 565.



2d. In this method we regard the sphere as being cut by plane inclined to the horizontal plane, and whose trace is $f\ d$. We find easily the inclination of the plane, because it is a tangent to the surface of the cone in the line $f\ e$, which is the horizontal projection of i E. We have thus a rectangular triangle, and $f\ e$ as one of its sides. Its second side is the axis of the cone, perpendicular to $e\ f$, and of which the height e E' is known, and the hypothenuse of the triangle is f E'. Conceive this triangle raised on its base $f\ e$, and we shall have an idea of the inclination of the plane $d\ f\ e$.

Now from k, the centre of the horizontal projection of the sphere, let fall upon $d\ f$ a perpendicular a b. This line will be parallel to $f\ e$, and will serve as the vertical plane for the projection of the sphere, as well as the inclined section plane. Raise upon a b, from the point e, a perpendicular, on which set off the height e E' from e to E". Then project f in f; draw f E", and we have the first right-angled triangle e f E", similar and equal to the first, and consequently we have also the inclination of the section plane in the angle e f E". Now, with the radius $k\ k'$ perpendicular to a b, describe a circle as the vertical projection of the sphere. We now see that this is cut by the inclined plane f E", or by the shadow of the cone in the line $o'\ p'$, one of the diameters of the circle of that section. Divide the horizontal projection $o\ p$ of that diameter in two equal parts at q; let fall from this a perpendicular on a b, cutting the circumference at the points $r\ s$, and the line $r\ s$ will be the major, and $o\ p$ the minor axis of the ellipse, which is the horizontal projection of the circle produced by the section of the sphere. This ellipse, or so much of it as we require, we can trace by means of a slip of paper. Having obtained this, we proceed in the same way in regard to the trace $h\ d$, and, the operations being completed, we transfer these shadows to the vertical projection, Fig. 556.

Fig. 566.

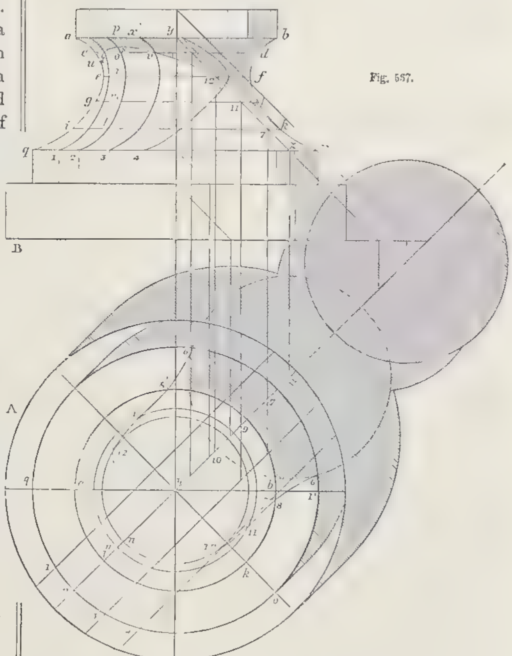


Problem XXIV.—*To determine the shadow of a concave surface of revolution.*

Let A B be the projections of the body, and 1 2 3 4, &c., traces of planes cutting it in the direction of the rays of light. Let us obtain first the vertical projection of the section 2, which will serve as a model for the others. Divide the concave part of the body B by horizontal sections $c\ d$, $e\ f$, $g\ h$, $i\ k$, which will be expressed by so many circles in figure A. In doing this we should avoid multiplicity of lines, by making as many of the circles as possible of the same diameter. Find now the vertical section on 2. It is evident that the first point 2 will be on the section $q\ r$ in 2; the second point l, will be on the section $i\ k$ in l, and also in $a'\ b$ in p; the third m, will be on $g\ h$, $c\ d$ in m and o; and the fourth n, on $e\ f'$ in n. Through $2\ l\ m\ n\ o\ p$ draw a curve, which will be the vertical projection of $2\ l\ m\ n$. Through p draw the projection of the ray, which will meet the curve in s, the first point of the shadow sought. Find in the same manner the points $w\ t\ v\ u$, &c., and through them draw the curve $w\ t\ v\ u$, which will be the portion of the shadow projected by the arc $a\ y$.

The point u belongs to the horizontal section 4, whose

Fig. 567.



vertical projection is very different from the others; and if we were to continue to operate in the same manner we should have the sections irregular, and the lines cutting too obliquely to give a precise result. Conceive, therefore, that the circle $q\ r$ is an indefinite horizontal plane, on which the shadow from $a\ b$ is to be thrown. To obtain this shadow we have only to draw through y (the vertical projection of the centre y) a ray meeting the plane $q\ r$ in z, and from z to let fall a perpendicular cutting the horizontal projection of the line of light passing through the centre y, and it will give z as the shadow of

the centre of the circle $a\ b$ on the horizontal plane of $q\ r$. As the circle is parallel to this plane its shadow will also be a circle of the same radius; therefore from the centre z, with the radius $a\ y$ or $b\ y$, describe the circumference cutting the horizontal circle $q\ o\ r$ in 6, which will be a point in the shadow sought, but as 6 is very near r, we can take without sensible error r as its vertical projection. Find then a point in the horizontal section $i\ k$ in the same manner. The ray $y\ z$ cuts the section $i\ k$ in the point 7. By letting fall from 7 a perpendicular, we obtain the centre 7, from which we describe a circle equal to the first, or simply an arc of it on the circumference $l\ k$ of the section $i\ k$, which gives a second point 8. Proceed thus with all the sections, which will give the centres 9, 10, &c., and the arcs 11, 12, of which the projections are 11, 12. Through the intersections of the arcs 12, 11, 8, 6, with the circles in A, draw a curve, which will be the horizontal projection of the shadow thrown on the concave portion of the figure, and the corresponding vertical projections are obtained by drawing perpendiculars from the same points to cut the sections $q\ r$, $i\ k$, $g\ h$, $e\ f$, in B. It is not necessary to describe the method of obtaining the remainder of the shadow on the horizontal projection, as an inspection of the figure, coupled with the previous problems, should be sufficient to enable the learner to do it.

METHODS OF SHADING.

Plates CIV.—CVI.

The intensity of a shade or shadow is modified by the various peculiarities in the forms of bodies, by the intensity of the light, and by the position which objects may occupy in reference to it.

Flat surfaces wholly exposed to the light, and at all points equidistant from the eye, should receive a uniform tint or *tone.*

In geometrical drawings, where the visual rays are imagined parallel to the plane of projection, every surface parallel to this plane is supposed to have all its parts at the same distance from the eye.

When two surfaces thus situated are parallel, the one nearer the eye should receive a lighter tint than the other.

Every surface exposed to the light, but not parallel to the plane of projection, and, therefore, having no two points equally distant from the eye, should receive an unequal tint. The tint should, therefore, gradually increase in depth as the parts of such a surface recede from the eye.

If two surfaces are unequally exposed to the light, the one which is more directly opposed to its rays should receive the fainter tint.

When a surface entirely in the shade is parallel to the plane of projection, it should receive a tint uniformly dark.

When two objects parallel to each other are in the shade, the one nearer the eye should receive the darker tint.

When a surface in the shade is inclined to the plane of projection, the part which is nearest the eye should receive the deepest tint.

If two surfaces exposed to the light, but unequally inclined to its rays, have a shadow cast upon them, the shadow upon the lighter surface will be more intense than that on the darker surface.

We shall now proceed to give some directions for using the brush, or hair-pencil, and explain the usual methods employed in producing this conventional tinting and shading.

The methods of shading most generally adopted are either by the superposition of any number of flat tints, or of tints softened off at their edges. The former method is the more simple of the two, and should be the first attempted.

Shading by Flat Tints.—Let it be proposed to shade the prism, *Fig.* 4, Plate CIV., or *Fig.* 3, Plate CVI., by means of flat tints. According to the position of the prism, as shown by its plan, *Fig.* 1, Plate CIV., one face, $a\ b$, is parallel to the plane of projection, and, therefore, entirely in the light. This face should receive a uniform tint, either of Indian ink or sepia. When the surface to be tinted happens to be very large, it is advisable to put on a very light tint first, and then to go over the surface a second time with a tint sufficiently dark to give the desired tone to the surface.

The right-hand face $b\ g$ being inclined to the plane of projection, should receive a graduated tint as it recedes. This gradation is obtained by laying on a succession of flat tints in the following manner:—First, divide the side into equal parts by vertical lines. These lines should be drawn very lightly in pencil, as they merely serve to circumscribe the tints. A grayish tint is then spread over the first division, $c\ b$ 11, *Fig.* 2. When this is dry, a similar tint is laid on, extending over the first and second divisions, and so on, till, lastly, a tint covering the whole surface imparts the desired graduated shade to that side of the prism, as in *Fig.* 3. The number of tints designed to express such a graduated shade depends upon the extent of the surface to be shaded; and the depth of tint must vary according to the number.

As the number of washes is increased, the whole shade gradually presents a softer appearance, and the lines which border the different tints become less harsh and perceptible. For this reason the foregoing method of representing a shade or graduated tint by washes successively passing over each other, is preferable to that sometimes employed, of first covering the whole surface, and then gradually narrowing the tint at each successive wash, because in this way the outline of each wash remains untouched, and presents, unavoidably, a harshness, which, by the former method, is in a great measure subdued.

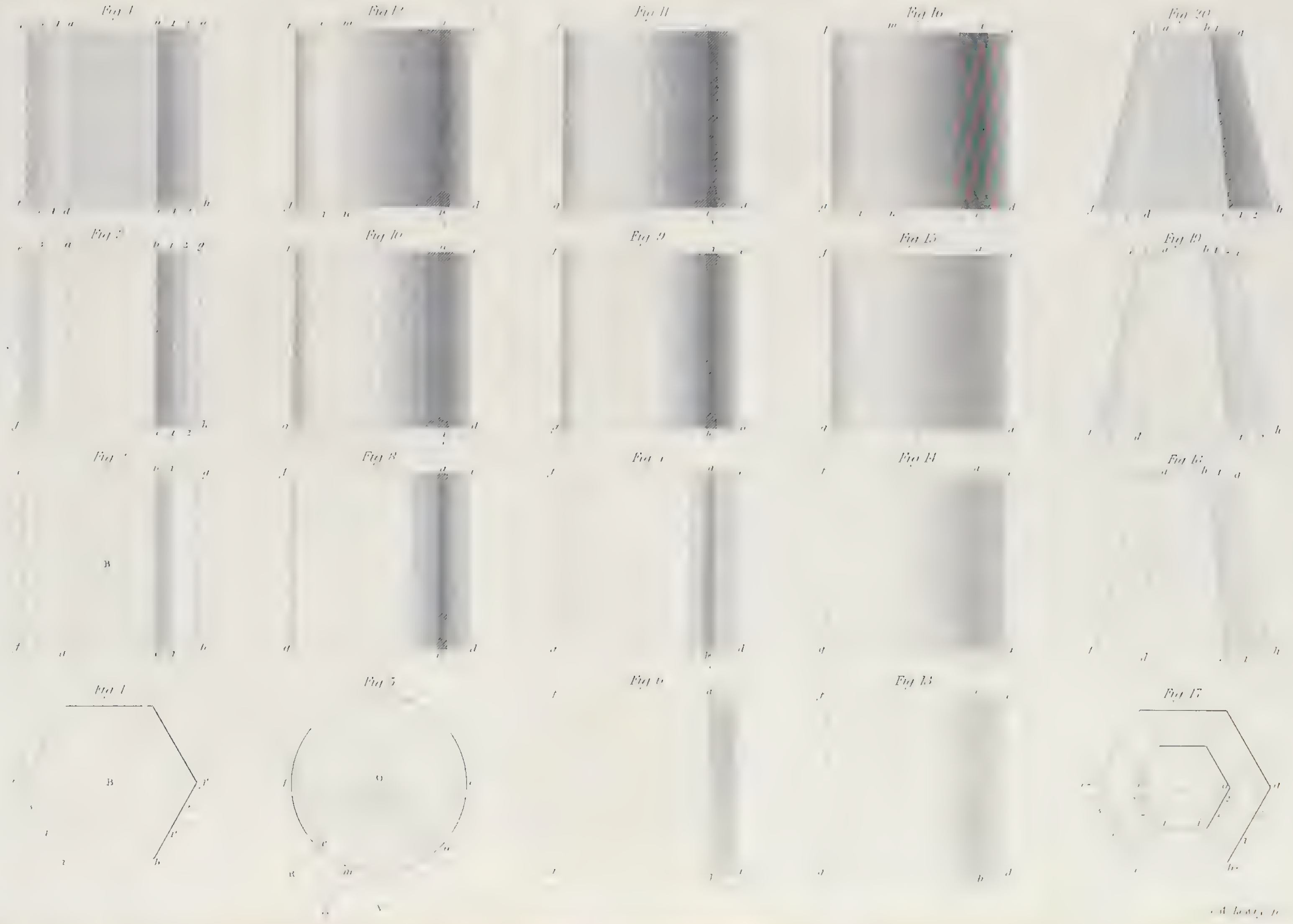
The left-hand face a is also inclined to the plane of projection; but, as it is entirely in the light, it should be covered by a series of much fainter tints than the last surface, which is in the shade. It should darken as it recedes. The gradation of tint is effected in the same way as before, as shown in *Figs.* 3 and 4.

Let it be proposed to shade a cylinder by means of flat tints, *Figs.* 5 to 12, Plate CIV.

In shading a cylinder it will be necessary to consider the difference in the tone proper to be maintained between the part in the light and that in the shade. It should be remembered that the line of separation between the light and shade, $a\ b$, is determined by the radius, $o\ a'$, *Fig.* 5, drawn at an angle of 45°, and perpendicular to the rays of light. That part, therefore, of the cylinder, which is in the shade, is comprised between the lines $a\ b$ and $c\ d$. This portion, then, should be shaded conformably to the rule previously laid down for treating surfaces in the shade

METHODS OF SHADING.

PLATE CIV.



inclined to the plane of projection. All the remaining part of the cylinder which is visible presents itself to the light; but, in consequence of its circular figure, the rays of light form angles varying at every part of its surface. In order to represent with effect the rotundity, it will be necessary to determine with precision the part of the surface which is most directly affected by the light. This part is situated about the line $e\ i$, *Fig.* 12, in the vertical plane of the ray of light, R O, *Fig.* 5. As the visual rays, however, are perpendicular to the vertical plane, and therefore parallel to V O, it follows that the part which appears clearest to the eye will be near this line V O, and may be limited by the line T O, which bisects the angle V O R and the line R O. By projecting the points e' and m', and drawing the lines $e\ i$ and $m\ n$, *Fig.* 12, the surface comprised between these lines will represent the lightest part of the cylinder.

This part should have no tint upon it whatever, if the cylinder happen to be polished—a turned iron shaft, or a marble column for instance; but if the surface of the cylinder be rough, as in the case of a cast-iron pipe, then a very light tint—considerably lighter than on any other part—may be given it.

Again, let us suppose the half-plan of the cylinder to be divided into any number of equal parts. Indicate these divisions upon the surface of the cylinder by faint pencil lines, and begin the shading by laying a tint over all that part of the cylinder in shade. This will at once render evident the light and dark parts. When this is dry put on a second tint, extending over that division which is to be deepest in colour, then spread a third tint over this division, and one on each side of it. Proceed in this way until the whole of that part of the cylinder which is in the shade is covered.

Treat in a similar manner the left-hand side, and complete the operation by covering the whole surface of the cylinder—excepting only the division in full light—with a very light tint.

Shading by Softened Tints.—The advantage which this method possesses over the one just described, consists in imparting to the shade a softer appearance; the limitations of the different tints being imperceptible. It is, however, more difficult.

Let it be proposed to shade by this method the former example of a prism.

Apply a narrow strip of tint to the nearest division of the shaded side, and then, qualifying the tint in the brush with a little water, join another lighter strip to this, and finally, by means of another clean brush moistened with water, soften off the edge of this second strip, which may be taken as the limit of the first tint.

When the first tint is dry, cover it with a second, which must be similarly treated, and should extend beyond the first. Proceed in this manner with other tints, until the whole face is shaded, as presented in *Fig.* 3, Plate CVI.

In the same way the left-hand face is to be covered, though with a tint considerably lighter, for the rays of light fall upon it almost perpendicularly.

Let it now be proposed to shade the cylinder, *Fig.* 7, Plate CVI., by means of softened tints.

The boundary of each tint being indicated as before, the first strip of tint must cover the line of extreme shade, and then be softened off on each side. Other and successively wider strips of tint are to follow, and receive the same treatment as the one first put on.

As this method requires considerable practice before it can be performed with nicety, the learner need not be discouraged at the failure of his first attempts, but persevere in practising on simple figures of different sizes.

If, after shading a figure by the foregoing method, any inequalities in the shade present themselves, such defects may be remedied, in some measure, by washing off redundancies of tint with the brush or a damp sponge, and by supplying a little colour to those parts which are too light.

Dexterity in shading figures by softened tints is best acquired in practising upon *large* surfaces; this is the surest way of overcoming timidity and hesitation.

Elaboration of Shading and Shadows.—Having thus laid down the simplest primary rules for shading isolated objects, and explained the easiest methods of carrying them into operation; it is now proposed to illustrate their application to more complex forms, to show where the shading may be modified or exaggerated, to introduce additional rules, and to offer some observations and directions for shading architectural and mechanical drawings.

Whatman's best rough-grained drawing-paper is better adapted for receiving colour than any other. Of this paper, the *Double Elephant* size is preferable, as it possesses a peculiar consistency and grain. A larger paper is seldom required, and even for a small drawing, a *portion* of a Double Elephant sheet should be used.

The paper for a coloured drawing ought always to be strained upon a board with glue, or by means of a straining frame. Before proceeding to lay on colour, the *face* of the paper should be washed with a sponge well charged with water, to remove any impurities from its surface, and to prepare it for the better reception of the colour. The whole of the surface is to be damped, that the paper may be subjected to a uniform degree of expansion. It should be only lightly touched by the sponge, and not rubbed. Submitted to this treatment, the sheet of paper will present, when thoroughly dry, a clean smooth surface, not only agreeable to work upon, but also in the best possible condition to take the colour.

The size of the brushes to be used will, of course, depend upon the scale to which the drawing is made. Long thin brushes, however, should be avoided. Those possessing corpulent bodies and fine points are to be preferred, as they retain a greater quantity of colour, and are more manageable.

During the process of laying on a flat tint, if the surface be large, the drawing may be slightly inclined, and the brush well charged with colour, so that the edge of the tint may be kept in a moist state until the whole surface is covered. If in tinting a small surface the brush should be too fully charged with colour, the surface will unavoidably present rugged edges, and an uneven appearance throughout. A moderate quantity of colour in the brush, well and expeditiously spread on the paper, is the only method of giving an even, close-grained aspect to the surface.

As an invariable rule let it be remembered, that no tint, shade, or shadow, is to be passed over or touched again until it is quite dry, and that the brush is not to be moved backwards and forwards through the colour.

In the examples of shading which are given in this

work, it may be observed that all objects with curved outlines have a certain amount of reflected light imparted to them. It is true that all bodies, whatever may be their form, are affected by reflected light; but, with a few exceptions, this light is only appreciable on curved surfaces. The judicious degree and treatment of this light is of considerable importance.

All bodies in the light reflect on the objects near them some of the rays they receive. The shaded side of an isolated object is lighted by rays reflected from the ground on which it rests, or from the air which surrounds it.

In proportion to the degree of polish, or brightness in the colour of a body, is the amount of reflected light which it communicates to adjacent objects, and also its own susceptibility of illumination under the reflection from other bodies. A polished column, or a white porcelain vase, receives and imparts more reflected light than a rough casting or a stone pitcher.

Shade, even the most inconsiderable, ought never to extend to the outline of any smooth circular body. On a polished sphere, for instance, the shade should be delicately softened off just before it meets the circumference, and when the shading is completed, the tint intended for the local colour may be carried on to its outline. This will give transparency to that part of the sphere influenced by reflected light. Very little shade should reach the outlines even of rough circular bodies, lest the colouring look harsh and coarse. Shadows also become lighter as they recede from the bodies which cast them, owing to the increasing amount of reflection which falls on them from surrounding objects.

Shadows, too, are modified in intensity by the air, as they recede from the spectator; they thus appear to increase in depth as their distance from the spectator diminishes. In nature this difference in intensity is only appreciable at considerable distances. Even on extensive buildings inequalities in the depth of the shadows are hardly perceptible; it is most important, however, for the effective representation of architectural subjects drawn in plan and elevation, that the variation in the distance of each part of an object from the spectator should at once strike the eye; and therefore a conventional exaggeration is practised. The shadows on the nearest and most prominent parts are made very dark, to give scope for the due modification in intensity in those parts which recede. The same direction is applicable to shades. The shade on a cylinder, for instance, situated near the spectator, ought to be darker than on one more remote. As a general rule, the colour on an object, no matter what it may be intended to represent, should become lighter as the parts on which it is placed recede from the eye.

Plate CV. presents some examples of finished shading. The remarks which we now propose to offer upon each of these figures are applicable alike to all forms of a similar character.

Fig. 1 represents a hexagonal prism surmounted by a fillet. The most noticeable part of this figure is the shadow of the prism in the plan view. It presents an example of the graduated expression which should be given to all shadows cast upon plain surfaces. Its two extremities are distinctly different in their tone. This difference is an exaggeration of the natural appearance necessary for the effect aimed at.

Figs. 2, 3, and 6 exemplify the complex appearance of shade and shadow presented on concave surfaces. It is worthy of notice that the shadow on a concave surface is darkest towards its outline, and becomes lighter as it nears the edge of the object. Reflection from that part of the surface on which the light falls, causes this gradual diminution in the depth of the shadow; the part most strongly illuminated by reflected light being opposite to that most strongly illuminated by direct light.

No brilliant or extreme lights should be left on concave surfaces, as they tend to render doubtful, at first sight, whether the objects represented are concave or convex. After the local colour has been put on, a faint wash should be passed very lightly over the whole concavity. This will modify and subdue the light, and tend to soften the tinting.

The lightest part of a sphere (*Fig.* 4) is confined to a mere point, around which the shade commences and gradually increases as it recedes. This point is not indicated on the figure, because the actual shade tint on a sphere ought not to be spread over a greater portion of its surface than is shown there. The very delicate and hardly perceptible progression of the shade in the immediate vicinity of the light point, should be effected by means of the local colour of the sphere. In like manner, all polished or light-coloured curved surfaces should be treated; the part bordering upon the extreme light should be covered with a tint of local colour somewhat fainter than that used for the flat surfaces. In curved unpolished surfaces, the local colour should be gradually deepened as it recedes from that part of the surface most exposed to the light. In shading a sphere, the best way is to put on two or three softened-off tints in the form of crescents converging towards the light point, the first one being carried over the point of deepest shade.

A ring (*Fig.* 5) is a difficult object to shade. To change with accurate and effective gradation the shade from the inside to the outside of the ring, to leave with regularity a line of light upon its surface, and to project its shadow with precision, require a degree of attention and care in their execution, greater perhaps than the shade and shadow of any other simple figure. The learner, therefore, should practise the shading of this figure, as he will seldom meet with one presenting greater difficulties.

Figs. 7 and 8 show the peculiarities of the shadows cast by a cone on a sphere or cylinder. The rule that the depth of a shadow on any object is in proportion to the degree of light which it encounters on the surface of the object, is in these figures very aptly illustrated. It will be seen, by referring to the plan (*Fig.* 7), that the shadow of the apex of the cone falls upon the lightest point of the sphere, and this is therefore the darkest part of the shadow. So also the deepest portion of the shadow of the cone on the cylinder, in the plan (*Fig.* 8), is where it comes in contact with the line of extreme light. Flat surfaces are similarly affected; the shadows thrown on them being less darkly expressed, according as their inclination to the plane of projection increases. The local colour on a flat surface should, on the contrary, increase in depth as the surface becomes more inclined to this plane.

These figures also show that shadows as well as shades are affected by reflected light. This is very observable where the shadow of the cone falls upon the cylinder.

Notwithstanding the most careful exertions of the colourist to keep every feature of a drawing clear and distinct, some amount of uncertainty, resulting from the proximity and natural blending of the different parts, will pervade the lines which separate its component members. For practical working purposes, therefore, a completely coloured drawing is unsuitable. On the other hand, a mere outline, although perhaps intelligible enough to those who are familiarly acquainted with the object delineated, has an undecided appearance. As complete colouring renders it difficult for the eye to separate the various parts, owing to an apparently *too* intimate relationship between them; a line drawing, on the contrary, perplexes the eye to discover any relation between them at all, or to settle promptly their configuration. The eye involuntarily asks the question, Is that part round or square, is it in the plane of the contiguous parts or more remote? As a means of avoiding the indefiniteness presented by the outline in the coloured drawing, and the want of adequate coherence and doubtfulness in the mere line drawing, recourse is not unfrequently had to a kind of semi-colouring, or rather shading and tinting the parts.

In this kind of drawing, it is advisable to follow a direction previously given, viz., to modify the colour on every part according to its distance from the eye. It may be as well also, for the purpose of maintaining harmony in the colouring, and of equalizing its appearance, to colour less darkly large shades than small ones, although they may be situated at an equal distance from the eye. The tinting should be very considerably lighter than on finished coloured drawings; and, indeed, no very dark shading should be employed. Besides presenting too violent a contrast between the parts coloured and those without any colour at all, dark shading would produce, in some measure, the indistinctness which is objectionable in completely tinted drawings.

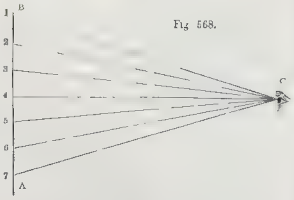
When, however, any architectural or other object is represented in perspective, the aim of the artist should be to avoid all the conventional exaggerations of which we have spoken, and to imitate to the best of his ability the appearance the object would have in nature.

PERSPECTIVE.

As an introduction to this study, it is necessary to observe, that a luminous point emits rays in all directions, and that all the points of the surface of a body are rendered visible by means of rays, which represent the axes of different cones formed by the emanation of bundles of rays from these points.

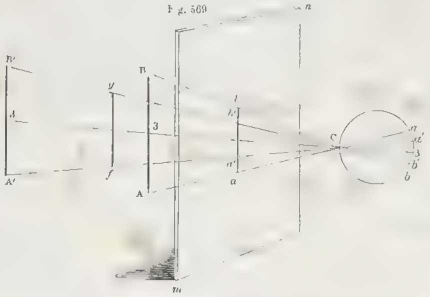
Let the line A B be placed before the eye C. It is evident that the sum of the visual rays which emanate from each of the points of that line to the eye, as 1 C, 2 C, 3 C, &c., forms a triangle 1 C 7, of which the base is 1 7 and the summit C. It is easy to see that if in place of the line a plane or curved surface is substituted, the result will be a pyramid of rays in place of a triangle.

Fig. 568.



Let A B (Fig. 569) be a straight line, and let the globe of the eye be represented by a circle, and its pupil by the point C.

Fig. 569



The ray emanating from A, entering through C, will proceed to the retina of the eye, and be depicted at *a*. And as it follows that all the points of A B will send rays, entering the eye through C, the whole image of A B will be depicted on the retina of the eye in a curved line *a* 3 *b*. Conceive the line A B moved to a greater distance from the eye, and placed at A′ B′, then the optic angle will be reduced, and the image *a*′ 3 *b*′ will be less than before; and as our visual sensations are in proportion to the magnitude of the image painted on the retina, it may be concluded that the more distant an object is from the eye, the smaller the angle under which it is seen becomes, and consequently, the farther the same object is removed from the eye the less it appears.

Observation has rendered it evident, that the greatest angle under which one or more objects can be distinctly seen is one of 90°. If between the object and the eye there be interposed a transparent plane (such as one of glass *m n*), the intersection of this plane with the visual rays are termed perspectives of the points from which the rays emanate. Thus *a* is the perspective of A, *b* of B, and so on of all the intermediate points; but, as two points determine the length of a straight line, it follows that *a b* is the perspective of A B, and *a*′ *b*′ the perspective of A′ B′.

It is evident from the figure that objects appear more or less great according to the angle under which they are viewed; and further, that objects of unequal size may appear equal if seen under the same angle. For draw *f g*, and its perspective will be found to be the same as that of A′ B′.

It follows, also, that a line near the eye may be viewed under an angle much greater than a line of greater dimensions but more distant, and hence a little object may appear to be much greater than a similar object of larger dimensions. Since, therefore, unequally-sized objects may appear equal in size, and equally-sized objects unequal, and since objects are not seen as they are in effect, but as they appear under certain conditions, perspective may be defined to be a science which affords the means of representing, on any surface whatever, objects such as they appear when seen from a given point of view. It is divided into two branches, the one, called *linear perspective*, occupying itself with the delineation of the contours of bodies; the other, called *aerial perspective*, with the

gradations of shade and colour produced by distance. The former of these only is proposed to be discussed here.

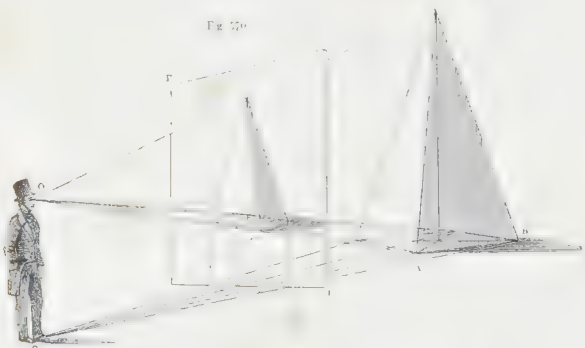
The perspective of objects, then, is obtained by the intersection of the rays which emanate from them to the eye by a plane or other surface (which is called the picture), situated between the eye and the objects.

From the explanation and definition we have just given, it is easy to conceive that linear perspective is in reality the problem of constructing the section, by a surface of some kind, of a pyramid of rays of which the summit and the base are given. The eye is the summit, the base may be regarded as the whole visible extent of the object or objects to be represented, and the intersecting surface is the picture.

A good idea of this will be obtained by supposing the picture to be a transparent plane, through which the object may be viewed, and on which it may be depicted.

Let us suppose any object, as the pyramid A B (Fig. 570), to be viewed by a spectator at C through a transparent plane D E. From the points of the pyramid visual rays will pass to the eye of the spectator, and if the points where they intersect the transparent plane be joined by lines on it, a representation of the object, as seen by the spectator, will be obtained. The transparent plane represents the picture, and the problem in perspective, is, as we have said, to make a section of the pyramid or cone of rays, as the case may be, by a plane, curved, or other surface. The figure illustrates the mode of doing this. A horizontal projection of the visual rays is made, that is

Fig. 570.

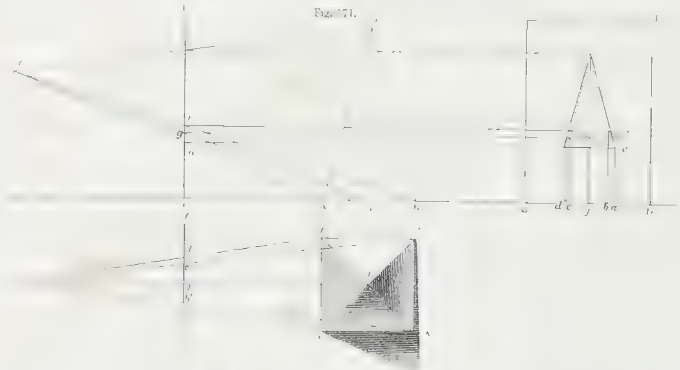


to say, from the plane or horizontal projection of the point required to be found in perspective, a line is drawn to the position or station point of the spectator, as A a C, and another line from its vertical projection to the eye of the spectator, as A a' O. At the points of intersection of the first set of lines with the horizontal projection of the picture, a perpendicular $a\ a'$ is drawn, and the intersection of this with the corresponding line from the vertical projection, gives the point a' required. All the other points are obtained in the same manner.

A much better idea of the mode of operation will be obtained from the following figures, in which the process is repeated geometrically. Let O and o' be the projection of the eye, E F $e\ f$ those of the picture, and A B G, $a\ b\ c\ d\ g$, of a pyramid with a square base.

Now, if from the eye a line is drawn to the points A a of the object, we shall have for the projections of that line, the lines A O, $a\ o'$. The points $a'\ a''$, where these projections cut the projections of the picture, are evidently the projections of the points in which the visual rays meet

Fig. 571.



the picture, and all that is required is to find the position of that point on the picture itself. Conceive E′ F′ to be the elevation of the face of the picture. To its base E′ D transfer the points $a''\ b''$, $b''\ g''$, $g''\ c''$, $c''\ d''$, in which the rays in the horizontal projection cut the picture, and from these points draw indefinite lines perpendicular to E′ D. On the line $a''\ a'$ set up from the base E′ D the height E a', in the vertical projection of the picture, and a' will be the perspective of the point required. Proceed in the same manner to obtain the other points.

As on the problem of finding the perspective of any point the whole science of perspective rests, the student should make himself thoroughly master of it, and although he may not be able to perceive the direct utility of what immediately follows, he is recommended to study it with care and attention, so as to understand the principles. The application of these will be developed by and by, and methods of abridging the labour will be pointed out; the student will also be enabled to devise others for himself.

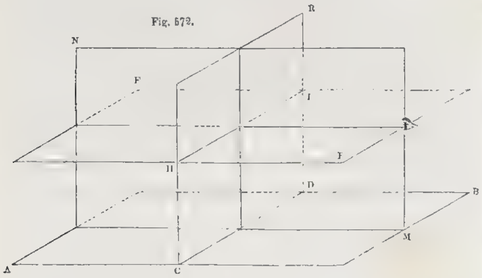
In addition to the vertical and horizontal planes with which we are familiar in the operations of projection, several auxiliary planes are employed in perspective, and particularly the four following:—

1. The horizontal plane A B (Fig. 572), on which the spectator and the objects viewed are supposed to stand; this is therefore generally termed the *ground plane* or *geometrical plane.*

2. The plane C R, which has been considered as a transparent plane placed in front of the spectator, on which the objects are delineated. It is called the *plane of projection* or the *plane of the picture.* The intersection C D of the first and second planes is called the *line of projection*, the *ground line*, or *base of the picture.*

3. The plane E F passing horizontally through the eye of the spectator, and cutting the plane of the picture at

Fig. 572.



right angles in the line H I, is called the *horizontal plane*, and its intersection with the plane of the picture is called the *horizon line, the horizon of the picture*, or simply *the horizon.*

4. The plane M N passing vertically through the eye of the spectator, and cutting each of the other planes in a right angle, is called the *vertical plane*, and sometimes the *central plane;* but as the term vertical plane is applied to any plane that is perpendicular to the ground plane, we shall use the term *central plane* for the sake of avoiding confusion.

Point of view, or *point of sight*, is the point where the eye is supposed to be placed to view the object, as at O (Fig. 571), and is the vertex of the optic cone. Its projection on the ground plane in Fig. 572 is M, and is termed the *station point.*

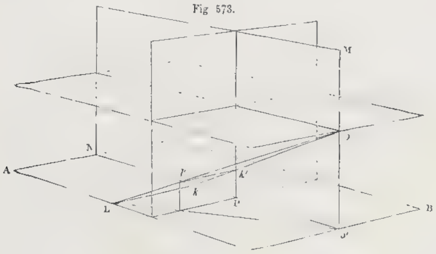
The projection of any point on the ground plane is called the *seat* of that point.

PROBLEM I.—*To find the perspective of a given point.*

Let k (Fig. 573) be the given point, draw the visual ray $k\ o$, which will meet the picture in k', the perspective of k, and it is only necessary now to know how to determine the position of k'.

Since o is the horizontal projection of the eye, if we draw $k\ o'$ it will be the horizontal projection of the visual

Fig 573.



ray from k. We shall then have a right-angled triangle, $k\ o'\ o$, which will be in the central plane M N, and will consequently be perpendicular to the ground plane A B. We have already seen that $k\ o$, the hypothenuse of this triangle, cuts the picture in k', and we perceive that the side $k\ o'$ of the triangle cuts the base of the picture in P; and as the two points P k' are in the plane of the triangle, and in the plane of the picture, the intersection of the picture and triangle will be the line P k'—whence it follows, that to determine in the picture the perspective of k, we draw from that point a line $k\ o'$, cutting the base of the picture in P; from P we elevate a perpendicular indefinitely; we draw then the visual ray $k\ o$, cutting this vertical line in k', which will be the point sought.

Observe that the triangle $k\ o\ o'$ is intersected in P k' parallel to its side $o\ o'$, and consequently the points of the triangle will be proportional among themselves; thus $k\ o' : o\ o' :: k$ P : P k', and the height of k', may be obtained by seeking a fourth proportional to the three lines $k\ o$, $o\ o'$, k P, which will be P k'. These three lines may always be known, for $k\ o'$ is the distance of the object from the position of the spectator o', called the station point; $o\ o'$ is the vertical height of the eye above the ground plane, and k P is the distance of the object from the picture. Thus the distance of the object from the station point, is to the height of the eye as the distance of the object from the picture is to the height of the perspective point in the picture.

The triangles $k\ o'\ o$, L $o'\ o$, are similar, since they are the same height, and are comprised between parallels. These triangles will therefore be proportional; thus l', the perspective of L, will have the same height in the picture as k', the perspective of k.

To obtain the perspective of L, therefore, we can use the triangle $k\ o'\ o$. To do this, project L upon the horizontal trace of the central plane, M N in the point k, which may then be considered as the vertical projection of L.

The remainder of the operation need not be described.

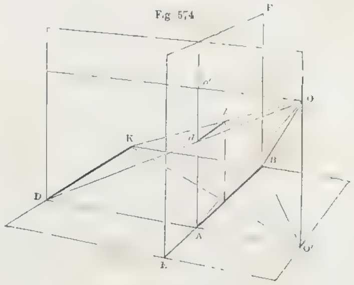
PROBLEM II.—*To find the perspective of a given right line.*

Let A B (Fig. 574) be the given line. From its extremities A B, draw to the eye of the spectator the rays A O, B O. It is evident that, as the picture E F is not cut by these rays, each of the points will be at the same time the original and perspective points. Hence we have:—

RULE I.—*When a straight line lies in the plane of the picture, it suffers no change, but its perspective representation is the same as its original.*

Let the line D K be situated in the ground plane, draw from its extremities d O, k O, the projections of the rays

Fig 574



D O, K O, and we have the triangle D O K, the base of which will be parallel to the line of projection; and consequently every point in its base, as D K, will be equidistant from the line of projection, and the height of all the points in the picture will be the same; therefore, the straight line between the points $d\,k$, which is the perspective of D K, will be parallel to the line of projection. Further, the triangle D O K will be cut by the picture parallel to its base D K, and the intersection $d\,k$ will therefore be parallel to that base and to the line of projection. From this we obtain—

Rule II.—*When an original line is parallel to the base of the picture, the perspective of that line will also be parallel to it.*

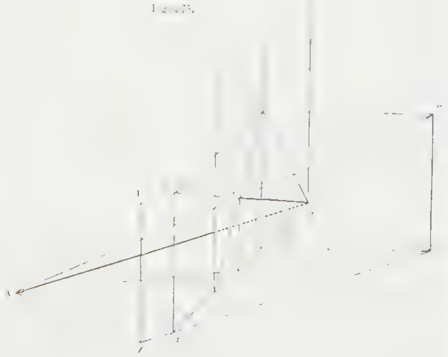
The line A D, it will be seen, is in the central plane; the triangle d A O is therefore also in that plane, and consequently vertical. The triangle, therefore, will cut the picture in the line A d perpendicular to its base. A d produced would be the trace of a plane perpendicular to the original plane, which would necessarily pass through the point of sight. The line A o' will also contain the projection of the vertical triangle D O' O, and the intersection of the triangle d A O with the picture will be the line A d, which is the perspective of A D, and it will tend to the projection of the point of sight.

The straight line B K, which is the base of the triangle K B O, is not in a plane perpendicular to the original plane, but inclined to it; for K B is beyond the central plane, while O is in that plane. Consequently, the projection of the inclined plane in which this triangle is situated, will be the triangle K B o' on the original plane, and its intersection with the plane of projection in the picture will be B o'; and, as the intersection B k is part of B o', the perspective B K is also directed towards the point of sight. It can be shown that this would also be the case with all other lines perpendicular to the picture; and therefore it can be concluded—

Rule III.—*The perspectives of all lines perpendicular to the picture pass through the point of sight.*

Let A B (Fig. 575) be a straight line, making with B C, the base of the picture, an angle of 45°. The perspective of the line will be a' B, which, being produced, would meet the horizon in the point d', and this will be the point of convergence of the perspectives of all lines parallel to A B. It is easy to perceive that the original line A B is the base of a scalene triangle A B E, formed by that line and the rays A E, B E, and which triangle has its base in the original plane, and its summit in the eye of the spectator. It will be inclined to both planes of projection, and will cut the picture in the line

Fig. 575.



a' B. The vertical projection of this triangle in the picture will be the triangle C e' B. Now, any triangle may be regarded as the moiety of a quadrilateral figure; therefore, if through E we draw a line E F parallel to B A, and another A F parallel to the ray B E, we shall obtain a quadrilateral figure A B E F, double the first triangle A B E, divided into two equal parts by the diagonal or ray A E. Since, then, the side E F is of the height of the eye, it will necessarily meet the plane of the picture at a point d' in the horizon, and the line d' B will be the intersection of the plane A B with the picture. Therefore the point d' will be the vanishing point of A B, and consequently of all the original lines parallel to it.

Suppose perpendiculars let fall from E F upon the original plane, and we obtain the points $e f$ as the projections of E and F, draw e B, $e f$, f A, and we have the quadrilateral A B, $e f$, for the horizontal projection of the inclined plane A E. The lines F E, $f e$, with the perpendiculars E e, F f, form a rectangle e F, or f E, which passes through the perpendiculars E e, F f. Consequently, this plane is vertical, and cuts the plane of the picture in the line $d\,d'$.

Observe that the lines E d', e d, being parallel to A B, make with the picture an angle of 45°, and therefore that E e is equal to e' d'. But E e' is the principal ray, or the distance of the eye from the picture, and therefore d' may be regarded as the point of distance carried upon the horizon from e' to d'. Hence we obtain—

Rule IV.—*The perspectives of all original lines making an angle of 45° with the picture, vanish in the point of distance.*

If the original line make a greater angle than 45° with the picture, its vanishing point will be found between the point of sight and the point of distance; and if a less angle, its vanishing point will be beyond the point of distance; and the general rule is thus expressed:—

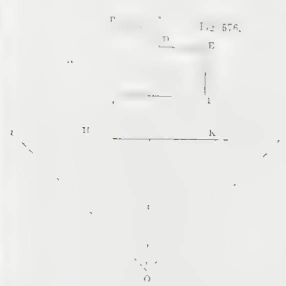
Rule V.—*The perspective of an original line, making any angle whatever with the picture, will have its vanishing point on the horizon at the intersection with the picture of a plane parallel to the original line passing through the point of sight.*

We have seen that the principal ray is necessarily parallel to the lines which are perpendicular to the picture, and that its intersection with the picture, or the point of sight, is the vanishing point for all such lines. We have seen, also, that the vanishing point of lines making an angle of 45° with the picture, is at the intersection with the picture of a line drawn through the point of sight parallel to the original line. And as in this, so in the case of any line making any angle whatever with the picture. Whence follows the general rule.

Rule VI.—*The vanishing point for horizontal straight lines, forming any angle whatever with the picture, is at the intersection with the picture of a parallel to these lines, drawn through the point of sight.*

To show this geometrically, let A B C D E F G (Fig. 576) be the horizontal projection, or plan of an original object, H K the picture line, and O the station point; then the vanishing point of A G, and all its parallels, will be found by drawing O a parallel to it, to intersect the picture line produced, when a is the vanishing point. The vanishing point of A B and its parallels will be b. The vanishing point of F E and all other lines

Fig. 576.

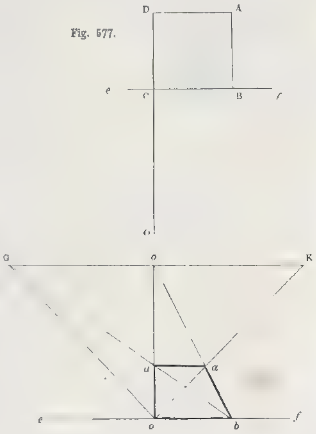


perpendicular to the picture will be the point of sight *e*; and the lines G F, B C, D E, being parallel to the picture, their perspectives will also be parallel to it.

The rules thus established, enable us to abridge, in many instances, the operations of drawing perspectives, as may be thus illustrated.

Let A B C D (Fig. 577) be the plan of a square, O the place of the spectator, *e f* the line of projection, and O C the central plane.

Fig. 577.



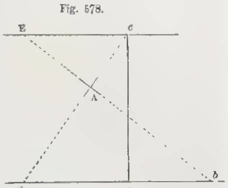
Draw *e f* to represent the vertical projection of the base of the picture, G K the horizontal line, *o* the point of sight, and *o o* the vertical plane. Then to draw the perspective of the square, transfer the side C D to *o b* (see Prob. I., Rule I.), and draw *b a*, which is the perspective of the side B A of the square produced to its vanishing point (see Prob. I., Rule III.) Then, as the diagonals of the square form an angle of 45° with the picture, from *o*, set off on the horizontal line *o* G, *o* K, each equal to the distance O C (see Prob. I., Rule IV.), and draw *b* G, *o* K, the perspectives of the diagonal produced to their vanishing points, and join the points *a d* where these intersect the perspectives of the sides by the line *d a*, parallel to the base of the picture (see Prob. I., Rule II.), and *o d a b* will be the perspective of the square.

If the perspective of the point A alone had to be sought, the operation would be simply to draw *b o*, and to intersect it by *o* K.

Let it be required, for example, to find the perspective of an original point A, situated 35 feet from the central plane of the picture, and 63 feet from the base.

Set off from any convenient scale from *o* to *f* (Fig. 578), 35 feet, and draw *f c*, *c* being the point of sight; set off from *f* to *b*, 63 feet, and draw to E, the distance of the spectator or point of distance, the line *b* E, and the intersection of the lines at A will be the perspective of the point required.

Fig. 578.



Let it be required to draw the perspective of a square, situated in the original plane, at any angle whatever to the plane of the picture. To solve this problem it is necessary only to find the perspective of a single point, which may be done in various ways.

Let A B (Fig. 579) be the plan of the square, O the place of the spectator or station point, E K the line of projection, and O *c* the central plane. We see that the point A is on the horizontal trace of the central plane, and at the distance A *c* from the picture, and that, therefore, the perspective of A is to be found on the central line, in the vertical projection O *c*. Set off the distance A *c*

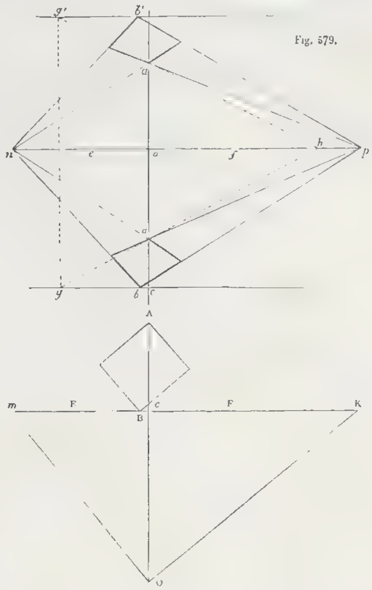


Fig. 579.

from *c* to *g*, and draw from *g* to the point of distance *h* the line *g h*, and its intersection with the central line at *a* is the perspective of A. Thus two points in the perspective are obtained, as B, being on the base of the picture, will have for its perspective *b*.

The vanishing points of the sides of the square are found to be K and *m*, by drawing parallels to these sides through O to meet the picture. Transfer the distances, therefore, K and *m*, to the horizon line *e f* in *n p*, and to these, from *b* and *a*, draw the perspective representations of the sides of the square. The operation is shown repeated above the horizon, the same parts being indicated by the same letters accented.

In the examples hitherto, we have operated by methods more or less indirect; it is now necessary to show the direct method of solving the same problems.

Let it be required to draw in perspective a square the same as the last. From the station point O (Fig. 580), draw to the angles of the square *a b c d* visual rays O *a*, O *b*, &c., and find the vanishing points *m′ k′* as before. Draw in the vertical projection the ground line *m k*, and the horizon *n p*, and transfer to the ground line the intersection of the visual rays with the picture; draw from *a* the lines *a m′*, *a k′*, and their intersections with the perpendiculars 1, 2, 3, will give the limits of the sides; then draw *a k′*, *b k′*, intersecting at *c*, which completes the square. If, as in the last figure, another square be drawn at a height above the given plane, equal to the side of the original square, we shall obtain the representation of a cube.

Let A B C D (Fig. 581) be the horizontal projections of four straight lines perpendicular to the picture B D, *b d*. The perspective of these lines *b a*, *d c*, *f e*, *h g*, will converge to the point of sight *i′*, and if the original lines were infinite, they would appear to meet in the point

of sight. These lines may be regarded as the boundaries of four planes, two horizontal, one $f\ g$ above, and the other $b\ c$ below the horizontal plane, and two vertical, $b\ c$, $d\ g$; and as the boundary lines of these planes may be considered as of infinite extent, so may also the planes themselves. It is obvious from the figure, that the perspectives of any line situated in a horizontal plane, can never in any case pass the horizon; that the horizon is in like manner the vanishing line of all horizontal planes; and that the trace of the central plane is the vanishing line for all vertical planes parallel to it.

In the example the vertical planes are shown to be squares, and their diagonals are consequently inclined to the picture in an angle of 45°. The perspectives of these diagonals will have their vanishing points in the vanishing lines of the planes which contain them, or in the trace of the central plane. The distance $i\ k$, $i\ l$ of these points $k\ l$, will be equal to the distance I i of the eye from the picture. The diagonals of the horizontal planes will have their vanishing points in the point of distance, as we have already seen. The plane A C being parallel to the picture, will have for its perspective the similar square $a\ e\ g\ c$.

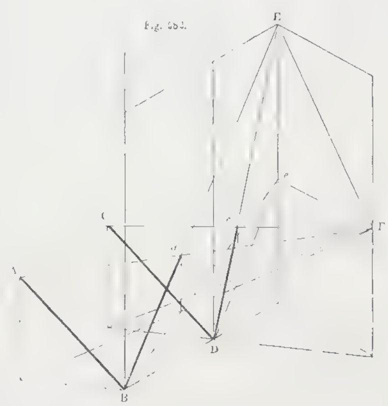
The line $b\ c$ is evidently inclined to the ground plane, and it is also situated in a vertical plane perpendicular to the picture. Its perspective will therefore have its vanishing point in the vertical of the picture, and in a point m which will be more or less high, as the inclination of the line is greater or less. The perspectives of the diagonals of the side $d\ g$ will have their vanishing points in $n\ m$. From this we deduce—

RULE VII.—*All lines inclined to the horizon, parallel among themselves, and inclined in vertical planes perpendicular to the picture, have their vanishing points in the vanishing line of the planes which contain them.*

RULE VIII.—*The perspectives of planes parallel to the picture cannot have vanishing points, but will always be of the same figures as their originals.*

Further to illustrate the vanishing points of inclined lines, let A B C D (Fig. 582) be two original parallel lines; their perspectives will be a B c D; the direction of which will be to the vanishing point E, situated at the intersection of the picture with a plane E f, passing through

Fig. 582.

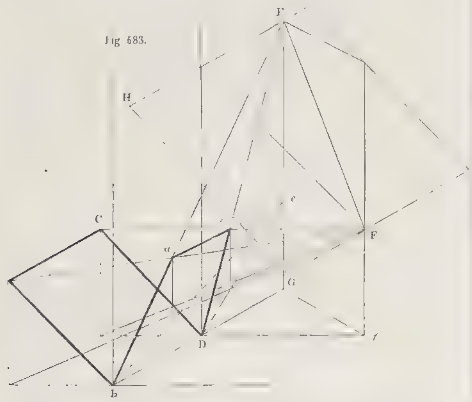


the eye F, parallel to the planes of the triangles A a B, C c D, passing through the given original lines.

The line F E is a line parallel to the given lines drawn through the eye to meet the picture. As it is in the plane E *f*, its intersection with the picture determines the vanishing points of the lines *a* B, *c* D.

This problem may be considered in a different manner. Let A B C D (Fig. 583) be the original lines as before:

Fig. 583.

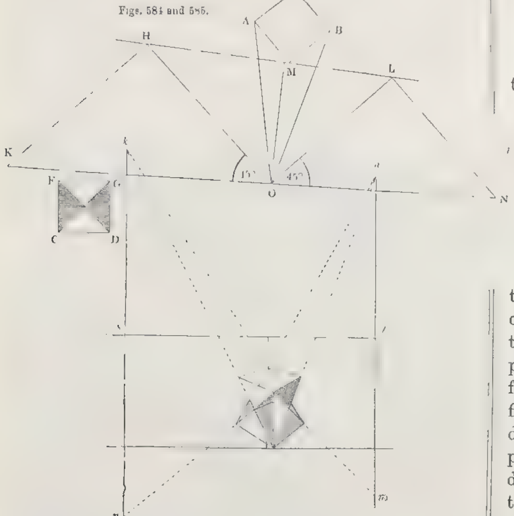


but in place of supposing them situated in two triangles, let us suppose them situated in a plane B C, inclined to the original plane. Let the plane G E, passing through the eye F, be parallel to B C, and let it cut the picture in the line H E, which, as we know, will then be the vanishing line for all planes parallel to B C. The line F E is drawn through the eye parallel to the original lines given, it lies in the plane G E, and cuts the picture in E. It lies also, however, in the plane *f* E, and therefore E is the vanishing point sought.

Let us consider the practical application of this problem, with the view to its more perfect elucidation:—

Let A B (Fig. 584) be the plan of a cube, and C D the

Figs. 584 and 585.



elevation of one of its sides, with diagonal lines drawn on it. Draw the visual rays O A, O B, the central plane O M, the picture line H L, and the lines O H, O L, to determine the vanishing points of the sides. Then to find the vanishing points of the oblique lines; from O in the ground plan, on the line O L, construct a right-angled triangle O L N, of which the angle N O L is equal to G C D, and set up the height L N, from *l* to *n*, in Fig. 585, which gives *n* as the vanishing point for C G and all lines parallel to it. Set the same length off downwards from *l* to *m*, and *m* is the vanishing point for F D, and all lines parallel to it. In the same way find the vanishing points on the left-hand side, by drawing the triangle O H K, and set off the length H K in *k* and *r* above and below the vanishing point *s* of the horizontal lines of the cube. The reason of this process is obvious, for we have only to imagine the triangles O L N, O H K, revolved round O L and O H until their plane is at right angles to the paper, and we then perceive that N and K are the heights over the horizontal vanishing points, that a plane passing through O at the height of the eye of the spectator, and at 45° with the horizontal plane, would intersect the plane of the picture.

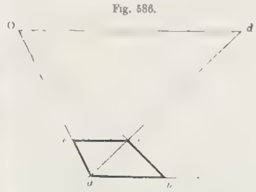
The drawing of the figure is explained by the dotted lines.

In what we have hitherto advanced are comprehended all the principles of perspective, and we shall now proceed to apply these principles in the solution of various problems.

Problem III.—*The distance of the picture and the perspective of the side of a square being given, to complete the square, without having recourse to a plan.*

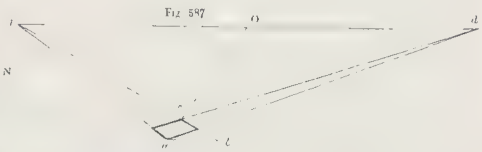
1st. When the given side is parallel to the base of the picture, let *a b* (Fig. 586) be the side of the square, O the point of sight, *d* the point of distance. Draw *a* O, *b* O, for the indefinite perspectives of the side, and *a d* for the perspective of the diagonal, and where it intersects *b* O in *c*, draw *c e* parallel to *a b*, and the perspective of the square is completed.

Fig. 586.



2d. When the diagonal of the square is perpendicular

Fig. 587



to the base of the picture, let *a* (Fig. 587) be the hither or nearest angle of the square, O the point of sight, *d d'* the points of distance. The diagonal of the square being perpendicular to the picture, will have the point of sight for its vanishing point. Draw, therefore, *a* O as its indefinite perspective. Set off from *a* to *b* the length of the diagonal, and draw *b d* intersecting *a* O in *c*, which is the perspective of the farther extremity of the diagonal; then draw the sides (which make angles of 45° with the picture) to the distance points *d d'*.

3d. When one side of a square is given, making any angle with the picture; let *a b* (Fig. 588) be the given side; produce it to the horizon in *c*. Set off the distance

of the eye on the central line, from E to F, and draw c F, which will be a parallel to the given side $a\ b$, and c is

consequently the vanishing point for all lines parallel to $a\ b$.

The point a belongs equally to two sides of the square, one the given side $a\ b$, the other the hither side of the square. Let us see how this latter is to be found. As this side makes a right angle with $a\ b$, from F draw F g at right angles to F c, and continue it till it meets the horizon. In this case the lines would extend beyond the limits of the paper, and to avoid that inconvenience we may adopt another method of working, viz., by the diagonal. Therefore, from F draw F d, making an angle of 45° with F c, and its intersection d with the horizon will be the vanishing point of one diagonal of the square. From F also draw F h, at an angle of 45°, with F c for the vanishing point h of the other diagonal.

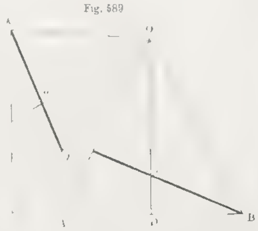
Now to complete the square, draw from the extremities of the given side the perspectives of the diagonals $a\ d$, $b\ h$, and produce the latter indefinitely; and to find the length of the sides, take the following means, founded on what has previously been learned.

Through the intersection of the diagonals at o draw a straight line $m\ n$, parallel to the base of the picture, and make $o\ n$ equal to $o\ m$, and n will be a point in the side of the square, through which draw $r\ s$, intersecting the diagonals, and join $b\ s$, $a\ r$, and the square is completed.

Problem IV.—*To divide a line given in perspective in any proportion.*

Let A B or B c (Fig. 589) be the given line, and let it be required to divide it into two equal parts. Now, A B being parallel to the base of the picture, will have its perspective exactly the same as the original, and if divided into equal parts, its perspective will also be divided into equal parts. But B c being oblique to the base of the picture will, in reality, be divided into two equal parts in the point e, although these parts appear unequal.

Fig. 589

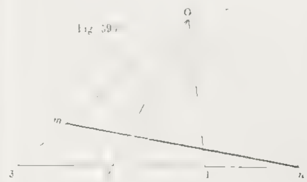


If through A and c we draw a line produced to the horizon, the point O will be the vanishing point of all lines parallel to A O. Hence, if we draw D O, B O, these three lines will be parallel among themselves. And as the lines A B, B c, are comprised within the parallels A O, B O, and are cut by the third parallel D O, it follows that their parts are proportional among themselves. And, therefore, if A D is the half of A B, $c\ e$ will be the half of B c.

The same will follow if the lines are in the vertical plane, as $k\ g$ divided into two equal parts in o.

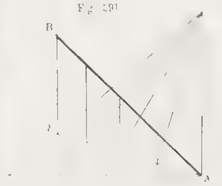
From what has been stated it will be seen that the problem reduces itself to these cases:—1. When the line is situated in a plane parallel to the picture, the divisions are made as in any other straight line. 2. When it makes any angle whatever with the picture, we draw through one of its extremities a line, either parallel to the base, or to the side of the picture, accordingly as the given line is situated in a horizontal or vertical plane, and we divide this line into the number of equal parts demanded; then through the last division, and through the other extremity of the given line, we draw a line produced to the horizón, and from all the points of division draw parallels to this line, which will, by intersection, give the perspective divisions of the line required. For example, let it be required to divide the line $m\ n$ (Fig. 590) into three equal parts; through n draw the horizontal line n 3 indefinitely, and set along it three equal divisions of the compasses, opened at pleasure in 1 2 3, through the last division, and through m draw a line to the horizon, intersecting it in O, which will be the vanishing point of all parallels to 3 O, and of course of the lines 2 O, 1 O, and by drawing these the perspective line $m\ n$ is divided into three equal parts.

Fig. 590



When the given line is inclined both to the picture and the ground plane, as A B (Fig. 591), it is necessary to find the divisions, first on its horizontal projection A b, and through them to draw vertical lines which will cut the perspective line in the points required.

Fig. 591

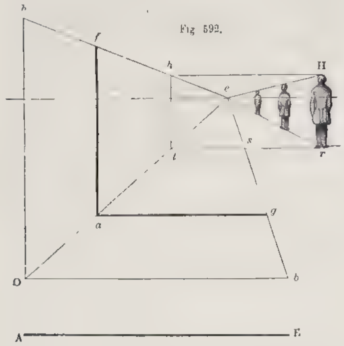


Problem V.—*Through a given point in a picture to draw a line parallel to the base or side of the picture, and perspectively equal to another given line* A B.

Let a (Fig. 592) be the given point. From it draw an indefinite line parallel to the base of the picture, or to its side, and then to determine on either of these lines a length perspectively equal to the given line, draw through a any line at pleasure, cutting the base of the picture, say at O, and the horizon at e. Set off from O a length, O b, equal to the given line, and draw $b\ e$, which will cut the indefinite horizontal line in g, and $a\ g$ will be equal to A B. In the same way proceed to obtain the length of the line $a\ f$ parallel to the side of the picture.

It is easy by this means to find the perspective height of a figure at any distance from the base of the picture. Let r, for example, be the point on the original plane at which the feet of a figure are supposed to be situated, and it is

required to know its height, and suppose A B the real height of the figure, then through r draw a horizontal

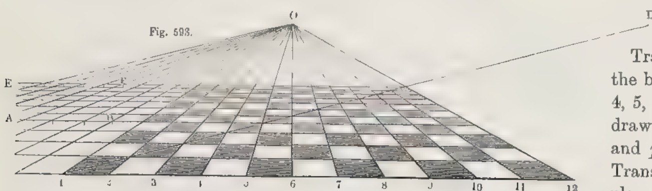


line cutting the parallels O e, b e, in s and t, and t s will be the height sought, which has to be carried vertically from r to H. Or otherwise, from the point of intersection t raise a perpendicular, which gives the point h, and t h will equally be the height sought.

PROBLEM VI.—*To draw the perspective of a pavement of squares, two of the sides of the squares being parallel to the base of the picture.*

The squares having two of their sides parallel to the case of the picture, their other two sides will have for their vanishing point the point of sight, and the point of distance will be the vanishing point of the diagonals.

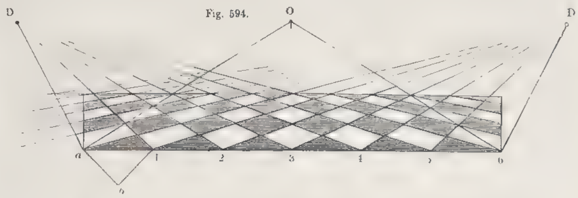
No plan is required. Set off on the base of the picture at 1 2 3, &c. (Fig. 593), divisions equal to the sides of the square, draw through these to the point of sight O, lines which are the perspectives of the sides of the squares, perpendicular to the picture, and intersect these by a diagonal drawn from any point, as 1 to D, the point of distance, and through the points of intersection draw lines parallel to the base of the picture. The squares can be extended so as to fill the picture by extending the base line and setting off more divisions. But if there is not room to do this, any of its parallels, as A B, may be pro-



duced, and the perspective lengths of the side of the squares set out on it, and again as at E F if necessary.

PROBLEM VII.—*To draw a pavement of squares in perspective, when the sides are inclined at angle of 45° to the base of the picture.*

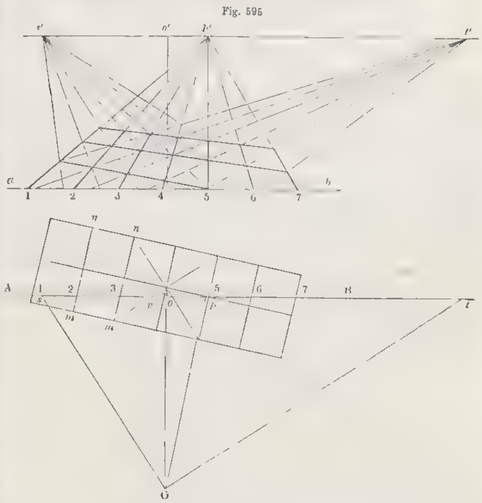
In this case let a b (Fig. 594) be the side of the square, and its diagonal will consequently be a 1. Lay off along the base of the picture the divisions 1 2 3, &c., each equal to the length of the diagonal. Now, as the sides of the square make angles of 45° with the picture, the distance points will be their vanishing points, and nothing more is required to be done than to draw from 1 2 3, and to D D the lines 1 D, 2 D. If it is required to fill the space from a or b draw a O, 6 O, which will be the perspective direction of the diagonals of the square, and their inter-



sections with the perspectives of the sides produced will give their points.

PROBLEM VIII.—*To draw the perspective of a pavement of squares, the sides of which form any angle with the picture.*

Let A B (Fig. 595) be the horizontal projection of the



base of the picture, cutting the squares (of which only two rows are here shown) at any angle.

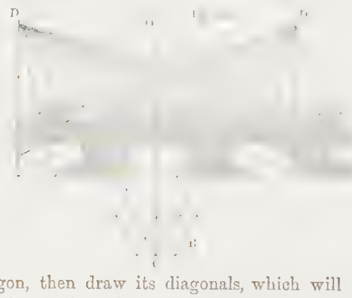
Transfer to the vertical projection a b of the base of the picture the divisions 1, 2, 3, 4, 5, 6, 7.* Through the seat of the eye O draw O p parallel to the sides of the squares, and p will be the vanishing point for them. Transfer the distance of p from the central plane o p to the horizon at o' p', and draw 1 p' 2 p', &c., which gives the perspectives of the sides of the squares parallel to m n, and we have now to find those which are perpendicular to them. This we might do by finding their vanishing points; but this mode would be inconvenient, as it would extend the vanishing point far beyond the limits of the paper, and we shall rather operate by the diagonals. Draw therefore through O, the seat of the eye, the lines O s, O t, parallel to the diagonals, to meet the picture-line produced in s t, and transfer o s, o t

* This is most conveniently done by transferring them first to the edge of a strip of paper, from which they can be transferred to the picture-line.

to the horizon-line in $o' s'$, $o' t'$. Then transfer the points 4 or v, where the diagonal meets the picture-line A B, to the vertical projection of the picture-line a b, and from these points draw lines to the vanishing points, as shown in the figure.

PROBLEM IX.—*To draw a hexagonal pavement in perspective, when one of the sides of the hexagon is parallel to the base of the picture.*

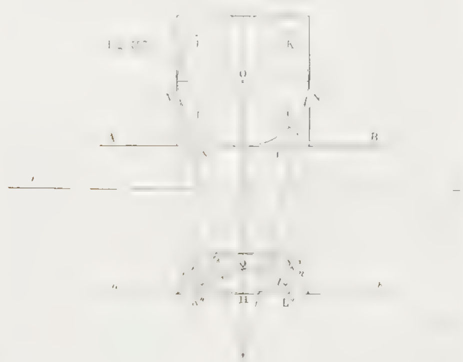
Let A B (Fig. 596) be the given hexagon. Set off along the base of the picture, divisions equal to the side of the



hexagon, then draw its diagonals, which will divide it into six equilateral triangles, and find the vanishing points of the diagonals. This may be done in the following simple manner. Let O be the intersection of the central plane with the horizon, and O C be equal to the distance of the spectator; then from C draw the lines C D, C D, parallel to the diagonals of the hexagon, and their intersection with the horizon in the points D D will be the vanishing points of the diagonals. The remainder of the operation requires no description.

PROBLEM X.—*To draw the perspective of a circle.*

Let A B a b (Fig. 597) be the projections of the picture,



c c those of the eye, o the point of distance, I J K L the given circle.

The most expeditious method of operating is to circumscribe the circle by a square. The circle touches the square at four points; and if the diagonals of the square are drawn, they intersect the circle at four other points, which gives eight points, the perspectives of which are easily found.

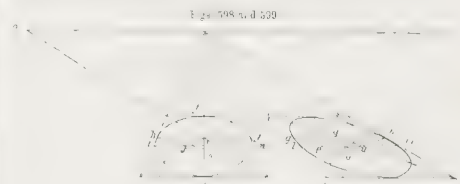
Thus, then, we draw the perspectives of the square and of its diameters and diagonals, and then project on the base of the picture a b the points I J K L in K′ and L′ and K″ and L″, and from these points draw the lines K″ c, L″ c, which cut the diagonals in i j k l, and through these and the four others E F G H the circle is to be traced by hand.

As the circle is a figure which has very frequently to be drawn in perspective, we shall consider it under another aspect.

Let there be any number of points taken in the circumference of the original circle (Fig. 597), and suppose lines drawn to them from the eye c, as the tangents M c, N c. Now it is evident that the collection of all these lines forms the projection of a scalene cone, having its base circular, and its summit in the eye of the spectator. Let us conceive this cone cut by the plane of the picture, and its section in the picture will be the perspective of its base or of the given circle. This operation can be performed by the rules of descriptive geometry, and the result will be the same as by the problem above. The perspective of this circle is, then, necessarily an ellipse, since it is the result of the section of a cone by a plane which passes through both sides, and is not parallel to its base. It is further to be observed, that in the ellipse the principal axis m n does not pass through the point o, the perspective of the original centre of the circle, but is the perspective of a chord M N, determined by the tangents M c N c.

PROBLEM XI.—*To inscribe a circle in a square given in perspective, and of which one side is parallel to the base of the picture.*

We know by the preceding problem that the ellipse should touch the four sides of the square in their apparent or perspective centres at the points e, f, g, h (Fig. 598). We can, therefore, consider the line e f as the minor axis of the ellipse which we seek; and as we know that the major axis should cross it perpendicularly in its centre,



we divide e f into two equal parts, and through i, the centre of the ellipse, draw perpendicularly to e f an indefinite line, which will be the direction of the major axis, of which we have to determine the length. Take f i, or i e, and carry it from h to j, and draw through h and j a straight line to the minor axis at k, and h k will be equal to half the major axis which we set off from i to l and m. Having now the major and minor axes of the ellipse, it is easy to draw it with the aid of a slip of paper, or in any other way.

In the next figure the same method may be thus applied:—

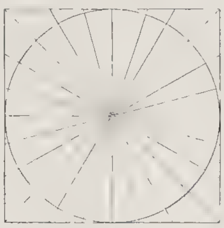
Let a c (Fig. 599) be the given square; through the intersection of its diagonals draw f e, and divide it into two equal parts in i, and through i draw an indefinite line parallel to g h. Through q, the perspective centre of the circle, draw a line perpendicular to g h, and produce it both ways, when it will cut the side d c in s, and the line l m in r. Carry the length s r from g or h upon l m to p or y, and draw g p or h y to cut s q in the point o,

and either of the lines $g\ p\ o$ or $h\ y\ o$ will be the rule with which to operate in describing the ellipse as before.

If it is required to divide the periphery of the circle into any number of parts, equal or otherwise, it may be thus performed:—

Though the points of division, on the geometrical plan of the circle (Fig. 600), draw radii, and produce them to intersect the sides of the circumscribing square. Then from the intersections visual rays may be drawn, and the corresponding points obtained in the perspective square, from which radii drawn to the perspective centre will cut the perspective circle in the points required.

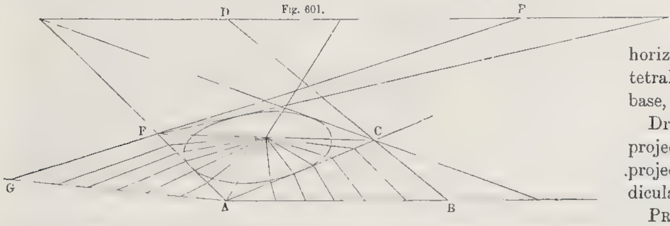
Fig. 600.



But we may in most cases dispense with the visual rays, and obtain the perspective divisions of the square by Problem IV., thus:—

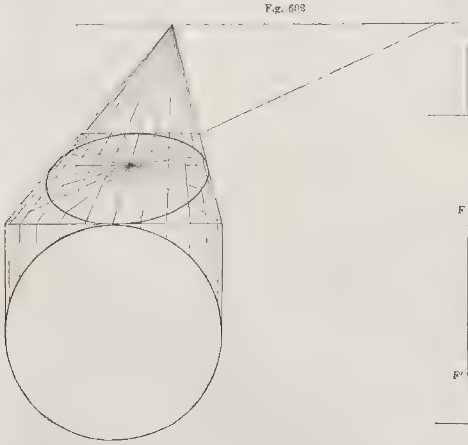
From the hither angle A of the square (Fig. 601) draw any line, as A B, A G, equal to the side of the square on the plan, and on it set off the intersections of the radii. Then from B draw through C a line cutting the horizon in D, and from G through F a line cutting the horizon in E, and from the divisions of the line A B, A G, draw lines to these points, which will divide A C, A F perspectively in

Fig. 601.



the same ratios, and from these divisions in A C, A F, draw radii to the perspective centre, which will divide the quadrants of the periphery of the circle, as required. Repeat the operation for the other sides.

Fig. 602



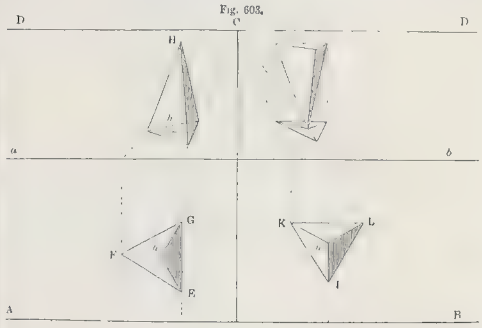
There is yet another method, which is of very great applicability.

Through the divisions in the plan of the circle (Fig. 602), draw lines parallel to one of the sides of the square, and produce them to intersect any of its sides, and from the perspectives of these intersections draw lines to the vanishing point of the side, to which the lines drawn through the divisions of the circle are parallel.

Perspective of Solids.

Problem XII.—*The horizontal projections of two tetrahedrons being given, to draw the perspective of the solid.*

Fig. 603.

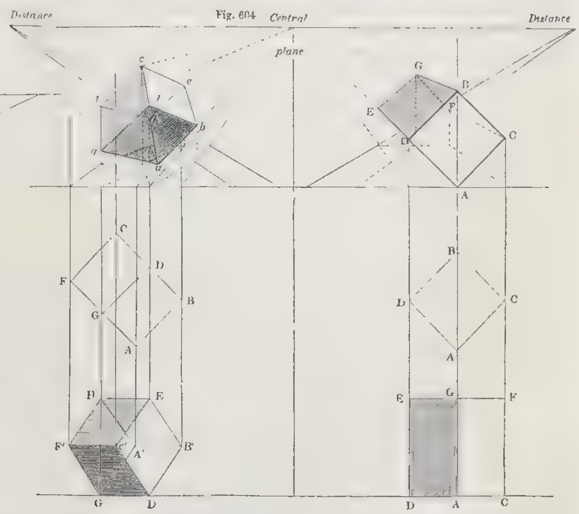


Let A B, $a\ b$ (Fig. 603) be the projections of the picture, C the point of sight, D D the points of distance, E F G h, I K L m the horizontal projections of the two given tetrahedrons, one of which is placed on its base, and the other on its summit.

Draw the perspectives of the horizontal projections, then through h, the horizontal projection of the summit, raise the perpendicular h H.

Problem XIII.—*The projections of two equal cubes being given* (Fig. 604), *one placed on one of its angles, and the other on one of its arrises, to draw them in perspective.*

Fig. 604



Here the operation is so simple that no explanation is required.

PROBLEM XIV.—*To draw three equal given cylinders in perspective* (Fig. 605).

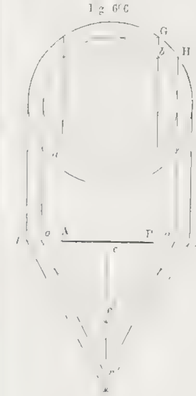
It is not necessary to repeat the method of putting a circle in perspective, but it may be well to observe, that

the upper surface of the cylinder may be so near the horizon that it is physically impossible to inscribe an ellipse. In such a case an approximate solution is all that can be arrived at. A few principal points should be obtained, and the ellipse traced by approximation.

This example presents a singularity, which at first sight appears a paradox, and yet is nothing less than that. The cylinder A, although evidently further from the eye than B, and seen consequently under a less angle, appears in the picture to have a greater diameter. The reason is, that its optical cone is cut more obliquely by the picture than that of B, and hence the intersection of A is longer. This, which is held to be a proof of the incorrectness of perspective, is, on the contrary, a proof of its correctness; for, if the subject is attentively considered, and we proceed to view the picture under the same conditions as to distance and height of the eye, as we have supposed to exist in viewing the object itself, we shall perceive that the representations of the objects must be seen under the same angles as the objects themselves, and therefore, although the diameter of the further column measures more in the representation than that of the nearer one, yet, from the proper point of view, the angle under which it is seen is less, and therefore it will appear to be smaller. The result, although geometrically correct, is yet a distorted representation, when viewed in the way we usually look at a picture. It is a correct section of the cone of rays, but not made by a plane so situated relatively to the object and spectator, as we should place a picture or a transparent plane through which to view the object. Before proceeding further, we shall take the opportunity of making some remarks on the conditions under which objects may be properly represented.

The greatest angle under which objects can be viewed with distinctness is one of 90°. But when viewed under this angle, it is with such an effort as to produce an uncomfortable sensation. Let us, however, suppose that we view an object under an angle of 90°, and we may consider the sum of the rays which can enter the eye under that angle as forming a cone, having the eye at its summit. Now, according to our proposition, the only objects which can be distinctly seen are those contained within the base of the cone. A picture is in this condition. Let a b, A B (Fig. 606), be the projections of the base of a square picture. Now, in order that this may be inscribed within the base of a right-angled cone, it is necessary that the axis of the cone be equal to the radius of the circle of its base. Thus from c', the centre of the picture, with c a or c b as radius, we describe a circle which contains the whole of the picture. We carry the radius in the horizontal projection from c to c', and the line c c' will of course be the shortest distance which we should take in order to see distinctly the picture A B. If we make a right angle at c', we shall have an isosceles triangle, of which the base o o will be equal to the diameter of the base of the cone. Now this distance c c', which is sufficient for the picture A B or a b, is too little for the picture a G, which has the same base as A B, but a greater height, or for a H, which has the same height, but a greater width; for neither of these are contained entirely within the optic cone o c' o, but require the base of the cone to be increased to p p. The distance, therefore, ought to vary with the height or width of the picture. So much for the principle; but we have said that a lesser angle than 90° is better to be adopted, and it is not easy to give any rule for this. In general, however, the distance should never be less than the diagonal of the picture, which would give o r o as the angle under which the square picture A B or a b should be viewed, and p s p for the others.

Fig. 606.



The distance, too, should depend in some measure on the height of horizon assumed, and in general the higher the horizon the greater should be the distance.

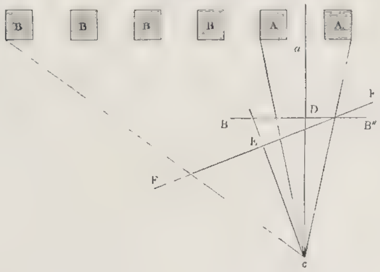
We now have to speak on a point to the misconception of which we attribute much that has been said against the art of perspective.

The central plane, it will be remembered, was defined to be "a plane passing vertically through the eye of the spectator, and cutting the ground plane, the horizontal plane, and the plane of the picture at right angles." Now let us take the horizontal projections of an object A A (Fig. 607), the picture B B, the eye of the spectator c, and the central plane c D a. The picture is parallel to the longest side of the object, and the central plane bisects the angle formed by the visual rays which proceed from the extremities of the object to the eye. This, then, we assume to be the correct conditions of a picture; but suppose it were required to introduce into the same picture other objects B B, as seen from the same point of view, we should no longer place the picture parallel to the long sides of the object, with the face of the spectator directed towards a, but we would again bisect the angle formed by the

visual rays proceeding from the extremities of the object to the eye of the spectator by the central plane c E, and make the line of the picture perpendicular to c E, as at F F.

Perspective has been divided into parallel and oblique perspective, and this division has introduced the miscon-

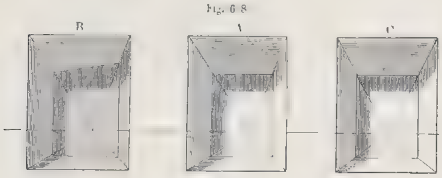
Fig. 607.



ception animadverted upon. Parallel perspective, so called, can only exist when the central plane, bisecting the angle formed by the visual rays, bisects also the object to be represented. Nevertheless, in views of interiors, of streets, and in architectural representations generally, it is unscrupulously used, although the intersection of the central plane with the picture is at one-third of the width of the latter.

In the figures C A B (Fig. 608), three different representations of the same interior are given to illustrate these

Fig. 608.



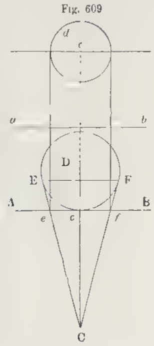
remarks. In fig. C the central plane bisects the visual angle; and the lines of the further side of the apartment, being parallel to the picture, are also parallel in the representation. In A the central plane does not bisect the visual angle, but is at one-third of the width of the picture; and this is the condition animadverted on. If it be desired to have the point of sight not in the centre of the apartment, like C, but at one side, then the representation is only correct when it is like B, in which the central plane bisects the picture, and the lines of the further side of the apartment being no longer parallel to the picture, have their proper vanishing points.

To revert to the example which has led to this digression, we observe by Fig. 605, that the distortion arises from assuming a position for the picture in which the central plane does not bisect the visual angle. But let us place the picture in the position E F, in which it is perpendicular to the central plane O C, bisecting the visual angle, and we have the cylinders in what is called oblique perspective (a distinctive term which should not exist), and there is no longer any distortion.

PROBLEM XV.—*To draw a sphere in perspective.*

Let $a\ b$, A B (Fig. 609) be the projections of the picture, $c\ c'$ those of the eye, the circle D that of the given sphere. If the centre of the sphere is at the height of the horizon, the vertical projection of its centre will be the point of sight c'. Draw from the eye c the tangents E c F c. Draw also the chord E F, which may be re-

Fig. 609

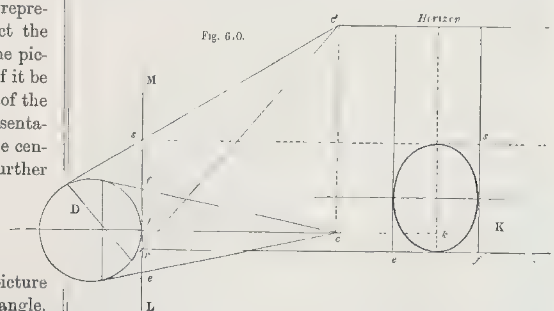


garded as the base of a cone formed by the visual rays, tangents to the sphere, and of which the eye c is the summit. The section of this cone by the picture will be a circle, since the cone is cut parallel to its base. This circle will have for its diameter $e\ f$; and consequently $c\ f$ or $c\ e$ as its radius. Then, if with this radius from the centre c' we describe a circle, it will be the perspective sought.

When the sphere is below the horizon, let D (Fig. 610) be the horizontal projection of a sphere, c that of the eye, and L M the picture-line. Draw visual rays tangents to the sphere, and we obtain on the picture-line $e\ f$ as the perspective horizontal diameter of the sphere. At K set off the diameter $e\ f$ so obtained, and from the points $e\ f$ raise indefinite perpendiculars. Now, suppose D to be the vertical projection of the sphere, and c' the vertical projection of the eye. From c' draw visual rays tangents to the sphere, and we obtain $r\ s$ as the intersection of the cone of rays by the picture, and the length $r\ s$ as the perspective vertical diameter of the sphere. But the diameter $r\ s$ is greater than the diameter $e\ f$, and therefore the perspective representation of a sphere viewed under the conditions premised, must be an ellipse. When we obtain the two diameters, we obtain all the measurements necessary for the representation of the sphere when below the horizon, and in the central plane, viz., the major and minor axes of the ellipse, and the curve may be trammelled by the aid of a slip of paper.

The point g in which the sphere touches the picture is the projection of its centre, and of its axis D g, and its perspective representation is k. In this there is another of those apparent contradictions, for it is certain that a

Fig. 610.



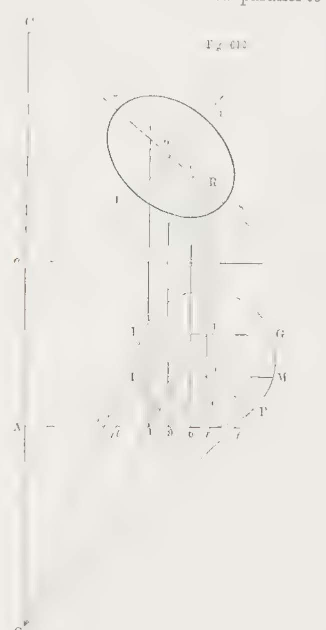
sphere always appears to us to be round on whichever side we regard it; while in perspective, in every case except that in which its centre is in the point of sight, it must be drawn an ellipse with its major axis directed towards the point of sight. An attentive consideration of the figures and description will render this evident, and the reader may also advert to the explanation of this apparent contradiction, which is given in the text treating of Figs. 605—607. We shall now proceed to give some other examples of spheres in perspective.

Let A B, $a\ b$ (Fig. 611), be the projections of the picture, C C′ those of the eye, D that of the given sphere in contact with the ground plane. Draw from the eye the tangents E C, F C, through E and F, draw parallel to the picture the

lines E G, F H, and draw also as many parallels to them, I K, O P, L M, &c., as may be considered necessary. These parallels, then, are traces of vertical planes cutting the sphere parallel to the picture, and all the sections made by them will be so many circles, which will comprehend all the visible portion of the sphere, as determined by the tangents E C, F C. The perspectives of the circles H F, I K, &c., which are parallel to the plane of the picture, will also be circles. If we envelope all these perspective circles by a curved line, this line will be the perspective of the sphere. It is easy to find the perspectives of the circles. First draw the diameter $r\ s$, which will be the horizontal projection of one of the axes of the sphere, passing through the centres of the circles H F, I K, L M, &c. Find then the perspective direction of that axis; observe that the point r is raised above the ground plane by the height of the radius of the sphere, and that it touches the picture. Its perspective consequently will be in R, and as the axis is perpendicular to the picture, its vanishing point will be the point of sight C′. Having drawn R C′, the perspective of the axis, find on it the centres of the circles. Find first the diameter of the circle E G; through l, the centre, draw l C, cutting the picture in l, and from l raise a vertical line cutting the axis R C′ in l', the centre sought. The radius l E has for its perspective the radius $l'\ e$, with which, from the perspective centre l, we describe the circle $e\ e$, and so on for all the other circles, and finally we circumscribe them by the elliptic curve.

This method is a little long, and has not all the precision which could be desired, for the two axes of the ellipse have not first of all been determined, which would simplify the operation; but this figure was necessary to show that the union of all the circles contains all the visible parts of the sphere, and forms an ellipse in the picture; and, moreover, it was absolutely required for the understanding of the following method, which is a consequence of it, but which is much more simple and precise.

After having drawn the tangents E C, F C (Fig. 612), the lines E G, F H, and found the point R, we draw the line R c, and produce it indefinitely towards R. We then seek on A B the intersections of the centres 1 6 of the circles E G, F H, and from 1′ 6′ raise to the picture verticals which cut the direction of the major axis in 1″ 6″. We take the perspective of the radius E 1, which is e 1 or 6 f, and in the picture from 1″ and 6″ as centres, and with e 1 or f 6 as radius, describe an arc to the right and left on R C′ to the points 7 and 8, and the line 7 8 will be the major axis of the ellipse. We divide this into two equal parts, and through the middle 9″ draw a line vertical to the picture-line $a\ b$, producing it to the horizontal projection of the picture-line A B, which it will cut in 9′. From the point of sight C we draw through this point a line produced to meet the diameter $r\ s$, and from the point of intersection 9′ we draw parallel to the picture

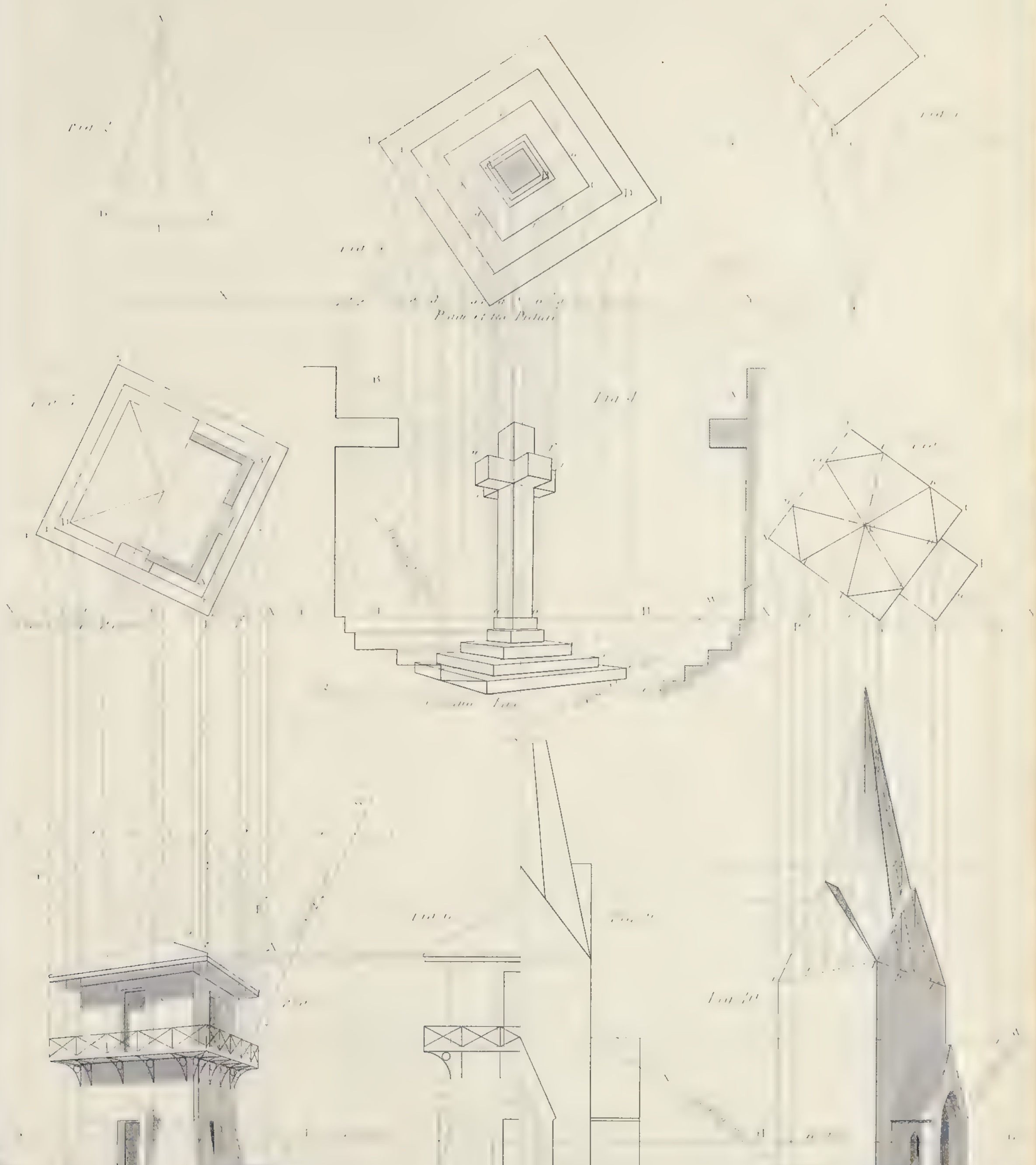


a line I M; from I we draw a line I c which cuts A B in l. We then take l 9′, the perspective of the radius L 9′, and from 9″ as a centre cut the direction of the minor axis in 10 11, and the minor axes will be determined. Having the two axes, the ellipse is easily traced.

Practical Examples of Perspective Drawing applied to Architecture, &c.—Plates CVII.—CXI.

Having thus described the principles of perspective, and shown their application to the drawing of elementary figures, we propose now, with the view to their more

PERSPECTIVE



perfect illustration, to show their application to the drawing of architectural and other objects.

Plate CVII.—*Fig.* 3 is the plan of a cross, and A W, *Fig.* 4, is a vertical section of the same.

Having selected the position of the spectator, or station point S, we draw from it visual rays, including as much of the object as we wish to represent. The angle included by these visual rays is then bisected, and the central plane S O drawn. The picture-line X Y is next drawn at right angles to the central plane, and then the vanishing points are found by drawing from the station point lines, S W, S V, parallel to the sides of the object, to intersect the picture-line. The point of intersection, or vanishing point, for the left-hand side of the figure, is at X; the vanishing point for the right-hand side, and the lines parallel to it, are beyond the limits of the paper. We have advisedly chosen in this case such a point of view for the picture, and such a distance as would throw one of the vanishing points beyond the limits of the paper, as such conditions of both station point and vanishing points are of constant occurrence in practice, and it is right that the learner should at the outset be made acquainted with the difficulties of the art and the means of overcoming them. These means in such cases may be two. The first and most ready is to fix slips of lath to the drawing-board, on which the horizon-line may be extended to the requisite distance. The other is to draw the converging lines by the centrolinead invented by Mr. Nicholson. This instrument, however, is not much used, probably because it requires frequent alteration to adjust it to the various vanishing points. We prefer the simple plan of fixing laths to the board, and inserting at each vanishing point a needle, against which the straight-edge may work as a centre. We shall now proceed to describe the process in detail.

We have already described the manner of drawing the extreme visual rays, picture-line, and central plane; these being drawn, we proceed to draw the visual rays from the various points of the plan E D C AB C DE, and *f f, f f, g g, g g*, and by producing to meet the picture-line X Y, the sides of the cross and the steps B *g* 1, C 4, D 5. From the points 1 2 3 4 5, where these intersect the picture-line, we let fall indefinite perpendiculars. These lines being in the plane of the picture will have the original heights of the object. Intersecting, therefore, these by horizontal lines from the different heights in the section of the cross A W, we obtain the heights of the different parts of the cross represented by the lines 1 2 3 4, brought into the plane of the picture. Now let us trace the drawing of any point in the plane, as A or B, to its perspective representation. From B, which is one of the angles of the shaft of the cross, draw the visual ray B *b* cutting the picture-line in *b*; and from *b* draw towards the ground plane of the perspective representation in *Fig.* 4 the line *b b*, which is an indefinite representation of the angle or arris of the shaft. Then, from the figure B H on the left, draw from the heights of the different horizontal divisions of the shaft, lines to the right-hand vanishing point, and we obtain their perspective heights on *b b*. In like manner we obtain the perspective representation of the points *ff, ff*, and the lines which join them, representing on the plan one of the limbs of the cross, by first drawing the visual rays, and then letting fall perpendiculars from the intersections of these with the picture-line, and intersecting these perpendiculars by lines drawn from the left-hand section B H to the vanishing point. It is not necessary to particularize further the drawings of this figure; the letters will enable the reader to follow the lines, and from his previous knowledge he will be able to reproduce a perspective so simple.

It will have been observed, that the labour of drawing is abridged and simplified by producing the lines of the object on the plan to the picture-line, a method of procedure which we shall adopt as much as possible in all the illustrations.

It may be as well here to show how an object may be drawn under any angle of view, that is to say, how the extreme visual rays may be made to include such an angle as may be determined upon. Let A B C D, *Fig.* 1, be any object, which it is required to delineate as seen from a point of sight G, under the angle of view A G C, &c. Let E F be the picture-line. In *Fig.* 2, construct on the base B C the triangle B A C, the included angle B A C being the angle required. Then, from the point C, *Fig.* 1, draw C G parallel to A B, and from A draw A G parallel to A C, meeting in the point G; bisect the angle A G C by the line G O, and at any required distance from the object draw E F perpendicular to G O, and the object will then be seen under the angle A G C equal to B A C, and E F will be the picture-line.

The next illustration is a pavilion, the plan of which is seen in *Fig.* 5, and the half elevation in *Fig.* 6. Let S be the station point. From S draw the extreme visual rays, including all parts of the plan, and bisect the angle by the central plane S O; then proceed to find the vanishing points by drawing from S the lines S W, S V parallel to the sides of the plan to meet the picture-line X Y, and from the various points of the building draw visual rays E *e*, F *f*, D *d*, &c., to meet the picture-line. Then, having drawn the ground line Q Z, *Fig.* 7, and the horizon-line H H, and the central plane S O, and set off on the horizon-line the right and left hand vanishing points: at the intersection of the visual ray from F, the hither angle of the building, let fall a perpendicular to the ground plane, *Fig.* 7. Produce F F, *Fig.* 5, to meet the picture in F′, and draw the perpendicular F′ F″. Then from F″, where this perpendicular meets the ground line, *Fig.* 7, draw a line to the left-hand vanishing point, to intersect the perpendicular from the visual ray of the point F, and we obtain the hither angle of the base of the building on the ground plane. In like manner produce D A to the picture in A′, and draw A′ A″, on which the heights for the hither angle of the body of the building are to be set up. The perspective height of the apex of the roof is obtained by producing the centre line of the building to the line of the picture, and on the perpendicular drawn from its intersection setting up the height of the apex. The hither angle of the balcony E E touches the picture-line, or comes into the plane of the picture, consequently is of the same height in the perspective as in the original. The divisions of the balcony railing are found by the application of Problem IV. as follows:—At any convenient place draw the horizontal line 6 1 6, and set off on it from 1 to 6 the divisions required; then from 1 draw to the vanishing points the lines 1 P, 1 P, intersecting the perpendiculars let fall from the visual rays of the further angles of the balcony. From 6 6 through these points of intersection P R draw lines as 6 P *p*, intersecting the horizon in *p*;

then to P as a centre draw radii from the points of division 2 3 4 5, and these will divide the line 1 P perspectively in the same ratio, and the divisions can be transferred to the balcony by drawing perpendiculars, as in the example

In the third example, which is that of a broach, or tower and spire, seen in plan in *Fig.* 8, and in half elevation in *Fig.* 9, the same method of procedure is adopted. On the plan, *Fig.* 8, the square tower A B C D, and its porch *g* E F *h*, are represented, and also the springing of the octagonal spire *f g h k l m n r*. The planes passing through the centre of the plan are produced in P P′ and P G to meet the picture-line, and the heights of the apices of the gables and the spire are set up on the perpendiculars let fall from P′ and G.

PLATE CVIII.—*To draw a series of arches in perspective.*

Let *Fig.* 1, No. 1, be the plan of the piers supporting the arches, and let *Fig.* 1, No. 2, be the elevation of an arch. From S, the station point, draw the visual rays, and find the vanishing points and the centre of the picture in the usual manner. Draw the ground line Q Z, and the horizon H H, and set off on the latter the centre of the picture and vanishing points. The perspectives of the semicircles, forming the arches, are shown obtained at M N in the plan, and M′ N′ in *Fig.* 1, No. 2, in the different methods illustrated in Problem IX., Figs. 600, 601, and 602. At M in the plan the intersections of the radii 1 2 3 4, No. 3, with the curve, and also with B F, are laid down at *o* 1 2 3 and *o*′ 1′ 2′ 3′, and from these points visual rays are drawn to Q Z, and from the points of intersection of these with the latter the perpendiculars 1 2 3 are drawn to meet the radial line drawn to the perspective centre O. The arch stones may be found in the same way, but in the figure they are shown as obtained by Problem II. The length of the line *a* E F, No. 2, is set off on any line *a f e*, and through *e* and F′, the perspective representation of F, a line is drawn to meet the horizon in D. The divisions of the arch stones on the line E F, No. 2, being then carried to the line *f e*, the perspective division of *a* F′ is obtained by drawing lines from the divisions in *f e* to D.

Another method of producing the perspective curve of the arch is shown at N on the plan, and at N′ in No. 2. Through any points in the arch *a* 1 2 3, lines are drawn to the plan in *a* 1 2 *o*, and *a*′ 1′ 2′ 3′, and corresponding lines *a* 1 2 *o* 1′ 2′, for the elevation; visual rays are drawn from the points in the plan, and perpendiculars raised on Q Z, at the points of intersection. To obtain the heights the line R S is produced to the plane of the picture in T, and T *b* is drawn perpendicular to Q Z, and on it are set up the heights of the pier T *c*, and of the divisions of the arch *a*′ 1′ 2′ 3′. Lines are drawn from these to the right-hand vanishing point, to intersect the perspective representation of the angle of the pier, and through these intersections *c a* 1 2 *b*, are drawn lines converging to the left-hand vanishing point, intersecting the corresponding perpendiculars.

To draw a circular vault pierced by a circular headed window.

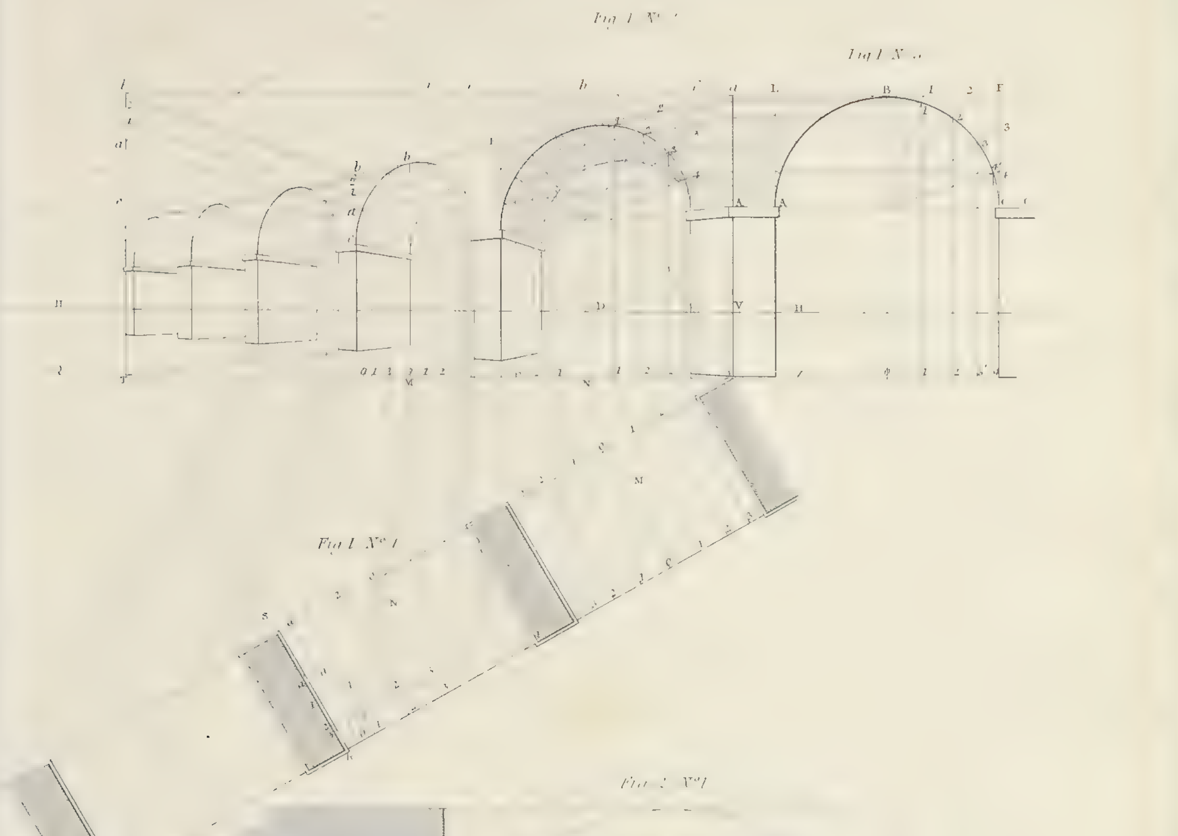
Fig. 2, No. 1, A C B is the elevation of the vault, and *Fig.* 2, No. 2, an elevation of its side, with F G H K L the circular headed window. Let S be the point of sight, and S D the distance of the spectator, that is D, the point of distance. The positions of the divisions G *o o*, *o o* K, are found by drawing from them lines to the point of distance, intersecting M N, the perspective representation of L M, and the perspective of the semicircle in the perpendiculars outside of the vault is found by the intersection of *d* D, C D, &c., with the vertical lines drawn through *o o o*. Through these intersections horizontal lines are drawn, and the points in which they are intersected by lines drawn to the point of sight S, through the divisions in the vault *d*′ *c*′ H, are points through which to trace the curve *d*″ *c*″ H″ of the circular headed opening.

PLATE CIX.—*To draw a Tuscan gateway in perspective.*

Having drawn the plan M M (*Fig.* 1), and fixed the station point S, draw the extreme visual rays S B^2, S B^3, and with any radius, from S as a centre, describe an arc R R cutting the rays, and from R R describe the intersecting arcs *t t*; draw the central line S O through the intersections, and the picture-line Y Z at right angles to S O. Then from S draw the necessary visual rays intersecting the picture-line, and produce also the leading lines of the object to intersect the picture. Draw the vanishing lines S V, S W. In *Fig.* 3 draw the ground-line G G, the horizon-line H H, and the central line O O. Proceed now to transfer the divisions on the picture line Y Z to the line F F, by describing arcs from N as a centre; and to draw the perspective, by carrying the heights from *Fig.* 2 to meet the lines let fall from the points where the corresponding lines of the members of the cornice intersect the picture-line, as shown by the faint lines in the plate; and from the points thus obtained draw lines to the right-hand vanishing point. Thus the height B (*Fig.* 2) is carried to B^4, to meet the line let fall from N, the intersection of B^2 B^3, *Fig.* 1, with the picture-line, and from B^4 a line is drawn to the right-hand vanishing point to meet the line *b* b^1, let fall from the intersection of the visual ray S B^2 with the picture-line; thus the heights b^1 b^3 are obtained. To obtain b^2 a line is drawn from b^1 to the left-hand vanishing point V^1, to meet the line let fall from the intersection of the visual ray S B^1 with the picture-line.

The pediment may be drawn by finding vanishing points for the inclined lines, as described at page 232, or in either of the following manners. Produce the centre line A A^1 (*Fig.* 1), to meet the picture-line in A^1. Transfer the point A^1 to F F in A^2, and let fall the perpendicular A^2 A^3. Draw horizontal lines from the heights of the pediment cornice intersecting this last line, and also the other intersecting lines of the different mouldings. From the heights on A^3 draw lines to the left-hand vanishing point V^2, and intersect them by lines drawn from the corresponding heights. For example, the height of the apex of the pediment A is carried to a^1 and A^3 (*Fig.* 3). From A^3 a line is drawn to the left-hand vanishing point, and from a^1 a line is drawn to the right-hand vanishing point, and their intersection at a^2 is the perspective height of the apex. The other method of drawing the pediment is by visual rays from the seats of the various members where they intersect the line A A^1 (*Fig.* 1), and then drawing the heights from the line A^2 A^3, to intersect the perpendiculars let fall from the points where these visual rays cut the picture-line. It is not necessary to give further details of the steps of the process, which must now be familiar to the student.

In making a complicated drawing, there is a multipli-



J. W. Lowry sculpt

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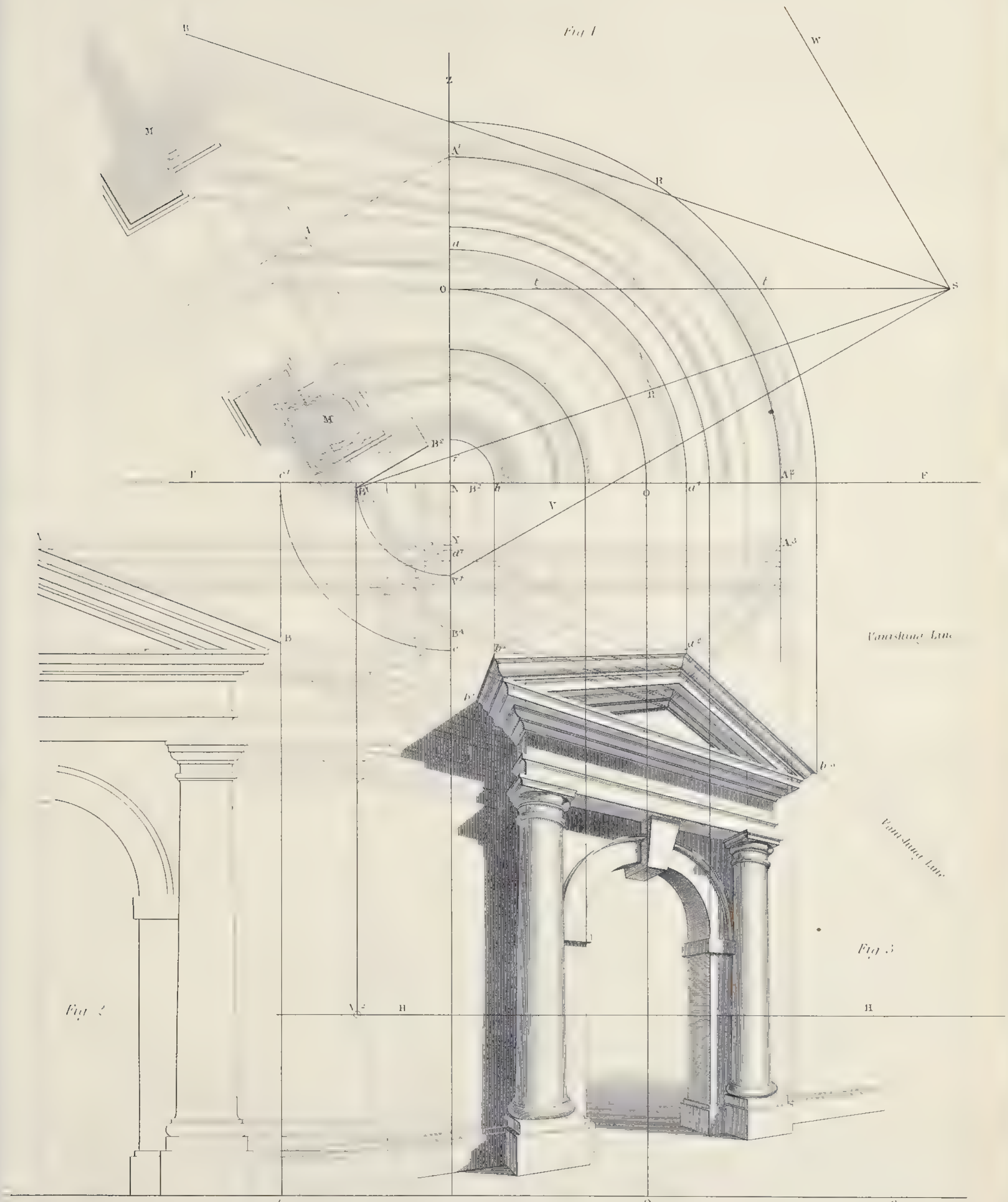
PERSPECTIVE.



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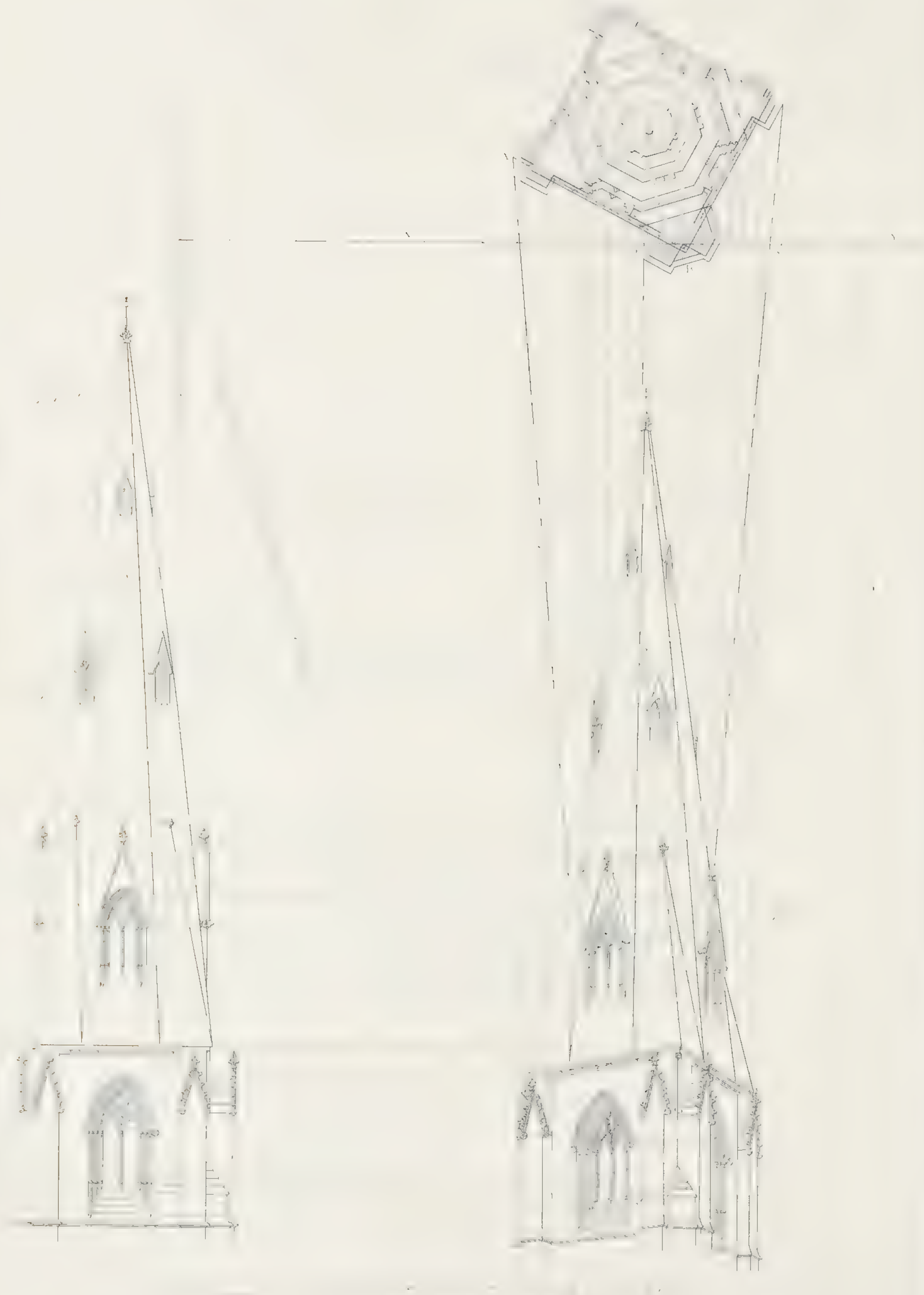

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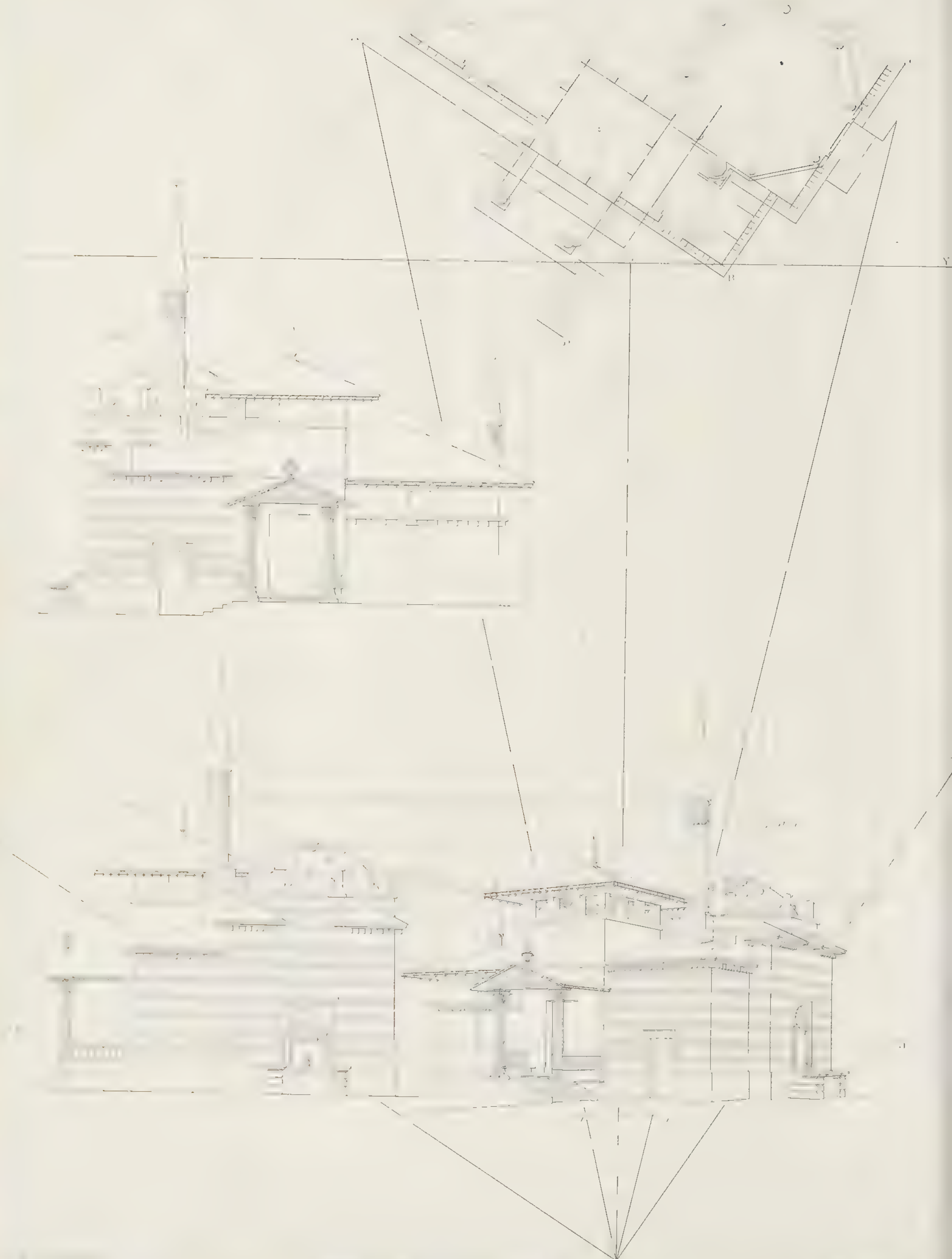


city of lines required, which tend to embarrass the learner. The lines of construction are of course first drawn in pencil, and only such portions of them as are eventually to appear in the work are drawn in ink; and it is well in practice, after the lines which are to appear in the drawing are obtained, to ink them in, and obliterate such lines used in obtaining them as are no longer required.

PLATE CX.—This plate is an example of the method of drawing a building in perspective. *Fig.* 1 is so much of the plan of the building, which is a Turkish bath, as is required for the operation, and *Figs.* 2 and 3 are elevations of the two sides under view.

The station S is first selected, and the extreme visual rays drawn and bisected by drawing the arc *a o b*, and thus obtaining the central line S O. The picture-line X Y is drawn at right angles to S O, and in contact with the hither angle of the building and the vanishing lines S V, S V are drawn parallel to the sides B C, B A respectively. The heights in the perspective are obtained, as in the former case, by producing the lines of the plan to intersect the picture, and then transferring the heights of the elevation (*Fig.* 3) to the corresponding perpendiculars let fall from these intersections.

The steps and terrace D are in advance of the picture, and their heights are obtained by setting them up on a perpendicular let fall from the intersection of the original line D with the picture, and drawing lines through them from the right-hand vanishing point, to intersect the perpendiculars let fall from the intersection of the visual rays. The plate shows all the lines of operation, and no further description is therefore necessary.

PLATE CXI. is an example of the method of drawing a Gothic broach or spire in perspective.

Fig. 1 shows horizontal sections of the spire at six different heights. The first is above the moulding of the tower, and shows the windows there; the second at the springing of the spire, the third at the first spire light, the fourth at the point where the lower pyramid terminates, the fifth at the second tier of lights, and the sixth at the third tier. *Fig.* 2 is the elevation of one side. Although apparently complicated, this figure is by no means difficult, and the student is recommended to reproduce this figure, or one of a similar kind, on a larger scale. The lines of operation, if carefully studied, will render description unnecessary.

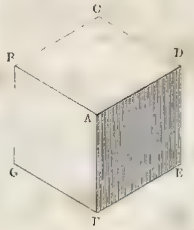
ISOMETRIC PROJECTION.

This is a conventional manner of representing an object, in which it has somewhat the appearance of a perspective drawing, with the advantage of the lines situated in the three visible planes at right angles to each other, retaining their exact dimensions. For the representation of such objects, therefore, as have their principal parts in planes at right angles to each other, this kind of projection is particularly well adapted. The name *isometrical* was given to this projection by Professor Farish, of Cambridge.

The principle of isometric representation consists in selecting for the plane of the projection, one equally inclined to three principal axes, at right angles to each other, so that all straight lines coincident with or parallel to these axes, are drawn in projection to the same scale.

The axes are called isometric axes, and all lines parallel to them are called isometric lines. The planes containing the isometric axes are isometric planes; the point in the object projected, assumed as the origin of the axes, is called the regulating point.

Fig. 613.



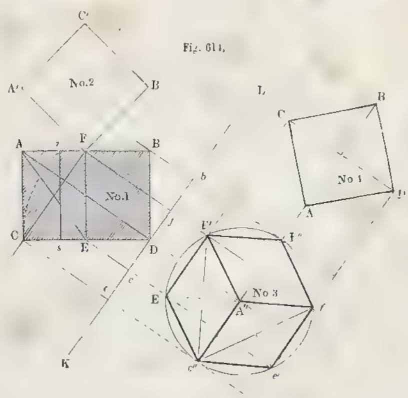
If any of the solid angles of a cube (Fig. 613) be made the regulating point, and the three lines which meet in it the isometric axes, then it may be demonstrated that the plane of projection, to be such that these axes will make equal angles with it, must be at right angles to that diagonal of the cube which passes through the regulating point. The projection of the cube will therefore be as A B C D E F G in the figure.

Let *r* B, *s* D (No. 1, Fig. 614) be the side of a cube, and *r* D, the diagonal of the side, produce *s* D, and make C D equal to the diagonal *r* D, complete the parallelogram C A, B D, and draw its diagonal A D, which is then the diagonal of a cube, of which *r* B D *s* is the side, and which is represented in plan in No. 2, A′ B′ C′ F′. Through D, draw K L at right angles to the diagonal A D, and K L is the trace of the plane of projection.

If to this line we draw through the points E C F B of the cube, lines parallel to the diagonal A D, and therefore perpendicular to K L, we find that the projection *c* D of the edge of the cube A C, is equal to the projections of the diagonals A B, C D, of the top and bottom surfaces of the cube, and we know that the projection of the other diagonal C′ F′ of the top (No. 2), and the projection of one diagonal on each side of the cube, will be equal to the original line, as they lie in planes parallel to the plane of projection.

Produce A D indefinitely, and at any point of it A″ (No. 3), with the radius D *c* or D *b* describe a circle. Draw

Fig. 614.



its other diameter B″ *c*″, and produce the lines E *e* F *f* through its circumference; join the points *c*″ E′ F′ B″ *f*′ *e*′ *c*″, to complete the hexagon, then join A″ F′, A″ *f*, and we have the isometrical projection of a cube, one of the sides of which is *r* B *s* D.

The lines drawn from the plan above (No. 4), show that the projection F′ *f* of the diagonal C D is of the same size as the original, and the triangle *c*″ F′ *f*, which

is the projection of the section of the cube by a plane CF' (No. 1), parallel to K L, the plane of projection, shows that the projection of one diagonal on each of the sides of the cube must also be of the same size as the original.

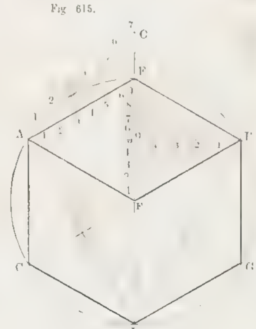
The relations of the lines of the projection to the original lines, are as follows:—The lines $c''F$, $F'f$, and $f'c''$, and all lines parallel to them, are equal to their original lines.

The isometrical axes and isometrical lines are to the original lines as ·8164 to 1.

The diagonals $A''B''$, $A''E'$, and AC' are to their originals as ·5773 to 1; or otherwise, calling the minor axis unity, then the isometrical lines are 1·41421, and the major axis equal to the original, is 1·73205, their ratio being as $\sqrt{1}$, $\sqrt{2}$, $\sqrt{3}$.

But in practice it is not necessary to find these lengths by computation; it is much more simple and easy to construct scales having the proper relation to each other, as we shall proceed to show in Fig. 615.

Fig 615.



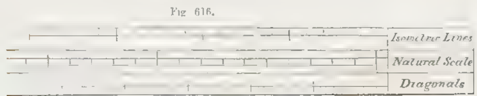
Let it be required, for example, to draw the isometrical projection of a cube of 7 feet on the side. Now, we have seen that the projection of one of the diagonals of the upper surface of the cube, is of the same size as the original. Draw, therefore, an indefinite line A B, and at any point of it A draw A C, making an angle of 45° with B A, and make A C from a scale of equal parts equal to the length of the side of the cube, which is here 7 feet. Also from A draw A E indefinitely, making an angle of 30° with B A. From C draw C O perpendicular to B A, and indefinitely produced, and cutting A E in E, then A E is the isometrical length of the side of the cube A C.

From A, with A E as radius, cut C O produced in F, and from F as a centre, with the same radius, describe a circle A E, B D; produce C F to D, draw AC' B G parallel to C D, and join DC', D G, and B E, and we shall then have a hexagon inscribed in the circle. Then draw the radii F A, F B, and we obtain the projection of the cube.

Now, divide A C into seven equal parts, and through the divisions draw perpendiculars to B A, cutting A E, and A E will be the scale for the isometric axes and lines, and their parallels.

The scale for E F, and the other minor diagonals, is made by drawing lines at an angle of 30° from the divisions of the original scale, set off on A B, intersecting the perpendicular E F. The divisions on E F form the scale for E F,

Fig 616.



FC', F G, and all lines parallel to them. As these ratios are invariable, scales may be constructed for permanent use, as in Fig. 616.

Although it is quite essential that the mode of forming scales for the isometric and other lines should be clearly understood, it is seldom that these scales require to be used in practice. For as we can adopt any original scale at pleasure, it is generally more convenient to adopt such a scale as we can apply at once to the isometrical lines. And in place of constructing the hexagon each time, it is convenient to have a set square with its angles 90°, 60°, and 30°, by means of which and a T-square or parallel ruler, all the lines of construction may be drawn.

Having assumed a scale, therefore, and fixed on the regulating point, suppose we wish to draw a cube, we proceed as follows:—From the regulating point F (Fig. 615), by means of the set square of 30°, draw the right and left hand isometricals F A, F B, and make them by the scale equal to the side of the cube. Then with the same set square, draw A E, B E, to complete the upper surface. Draw, by means of the set square of 90°, AC', F D, B G, make them equal to F A, or F B, and, by the aid of the set square of 30°, join DC', D G, and the cube is completed.

The following figures illustrate the application of isometrical drawing to simple combinations of the cube and parallelopipedon. In Fig. 617, one mode of construction

Fig 617.

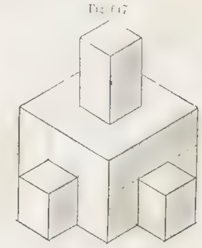


Fig 618.

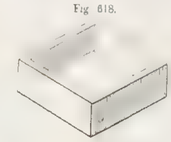
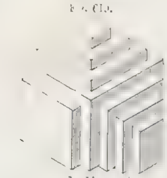


Fig 619.



is shown by dotted lines, but we may proceed directly as in drawing the cube in the manner above described, beginning at the hither angle of the largest block on the figure, and adding the minor parts. Fig. 618 shows the interior of what may be considered a box or a building. Fig. 619 requires no description.

The following figures show how lines which are not isometric may be obtained by the aid of those which are.

Fig 620.

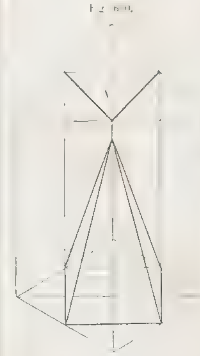
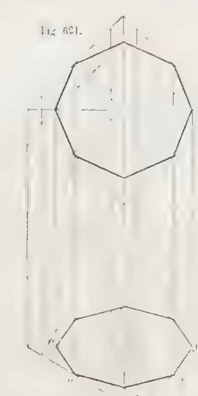


Fig 621.



In Fig. 620, A is the half-plan of a pyramid with a

square base. By including it in an isometrical square, its projection is readily obtained.

Fig. 621 is an octagon, Fig. 622 a hexagon, and Fig. 623

Fig. 622.

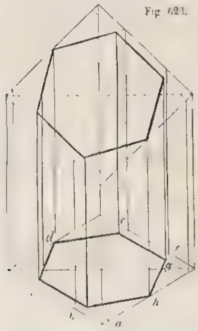
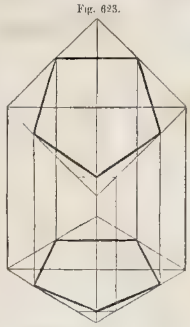


Fig. 623.

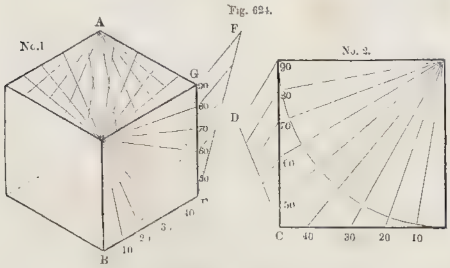


a pentagon. The projections are obtained by the intersections of their lines, or their lines produced with the sides of the circumscribing square; and it may be observed by these examples, that the projection of any line making any angle whatever with the isometric lines, can be very easily obtained. In the figures, all the lines of construction arising from the various intersections are shown for the sake of illustration. But in practice it is easily to be seen, that it is only necessary to obtain a few of the intersections. As for example, in Fig. 621, the points *a b c d e f*, and in Fig. 622 the points *a b c d e f g h*.

We shall now proceed, in Fig. 624, to show how the projection of lines at any angle may be obtained directly.

Let A B, No. 1, be the isometrical projection of a cube, on any of the sides of which it is required to draw lines at various angles. Draw a square, No. 2, and from any of its angles describe a quadrant, which divide into 90°, and draw radii through the divisions meeting the sides of the square. These will then form a scale to be applied to the isometric faces of the cube, No. 1; thus, from E, or any other angle of the cube, draw a line E F at any angle; make it equal to the side of the square, No. 2, and transfer the divisions of that side to it. Join G F, and draw parallels to G F through the other divisions of E F, meeting E G, which they will divide in the same proportion, and repeat the operation to find the divisions of the remaining sides; or from the angle C of the square, No. 2, draw a line C D,

Fig. 624.

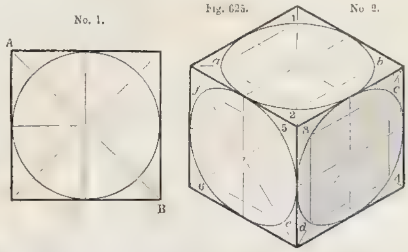


and make it equal to E G, and draw parallels in the same manner. As the figure has twelve isometrical sides, and the scale of tangents may be applied two ways to each, it can be applied, therefore, twenty-four ways in all. We thus have a simple means of drawing, on the isometrical faces of the cube, lines forming any angles with their boundaries.

We have now to consider the application of this species of projection to curved lines.

Let A B, No. 1, Fig. 625, be the side of a cube with a circle inscribed; and suppose all the faces of the cube to have similarly inscribed circles. Let us draw the isometrical projection of the cube, No. 2. Then, as the pro-

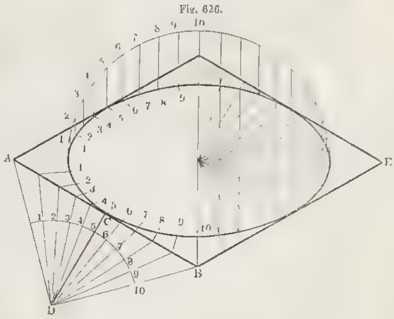
Fig. 625.



jection of one of the diagonals of each face of the cube, and consequently one of the diameters of the circle, is of the same size as the original, we have at once the major axis of the ellipse which the projection of the circle forms, and as the circle touches each side of the square, we have also four points in the circumference of the ellipse, and we have only to find the isometric projection of its minor axis. From the intersections of the diagonals of the faces of the cube, set off on the major axis the radius of the circle at *a b c d e f*, and through the points thus obtained draw isometric lines cutting the minor axis in 1 2 3 4 5 6, and we thus obtain the length of the minor axis. The ellipse can then be sketched by hand, or trammelled by a slip of paper.

We may divide the circumference of a circle in two ways, as shown in Fig. 626. First, on the centre of the line A B erect a perpendicular C D, and make it equal to C A or C B. Then from D with any radius, describe an

Fig. 626.



arc, and divide it in the ratio required, and draw through the divisions, radii from D, meeting A B. Then from the isometric centre of the circle draw radii from the divisions on A B, cutting the circumference of the circle in the points required.

Second, on the major axis of the ellipse describe a semicircle, and divide it in the manner required. Through the points of division thus obtained draw lines perpendicular to A E, which will divide the circumference of the ellipse in the same ratio. On the right hand of the figure both methods are shown in combination, and the intersection of the lines gives the points in the ellipse.

Mr. Nicholson, in his *Treatise on Projection*, has given the following table of the isometric radius, semi-axis minor, and semi-axis major of ellipses, from 1 inch to 9 feet; which, in certain cases, may be found useful:—

Isometric Radius.		Semi-axis Minor.		Semi-axis Major.		Isometric Radius.		Semi-axis Minor.		Semi-axis Major.		Isometric Radius.		Semi-axis Minor.		Semi-axis Major.	
Ft.	Ins.	Ft.	Ins.	Ft.	Ins.	Ft.	Ins.	Ft.	Ins.	Ft.	Ins.	Ft.	Ins.	Ft.	Ins.	Ft.	Ins.
0	1	0	[illegible]	0	[illegible]	3	1	2	2	3	9¼	6	1	4	3⅔	7	[illegible]
0	2	0	1½	0	[illegible]	3	2	2	[illegible]	3	10½	6	2	4	4⅓	7	6½
0	3	0	2	0	3	3	3	2	[illegible]	3	11¾	6	3	4	5	7	8
0	4	0	[illegible]	0	[illegible]	3	4	2	[illegible]	4	1	6	4	4	5¾	7	9
0	5	0	[illegible]	0	6	3	5	2	5	4	2	6	5	4	6⅓	7	[illegible]
0	6	0	[illegible]	0	7⅓	3	6	2	[illegible]	4	3⅓	6	6	4	7	7	[illegible]
0	7	0	[illegible]	0	[illegible]	3	7	2	[illegible]	4	[illegible]	6	7	4	8	8	[illegible]
0	8	0	[illegible]	0	[illegible]	3	8	2	7	4	[illegible]	6	8	4	[illegible]	8	2
0	9	0	[illegible]	0	11	3	9	2	7¾	4	7	6	9	4	9¼	8	3
0	10	0	7	1	0¼	3	10	2	[illegible]	4	[illegible]	6	10	4	10	8	[illegible]
0	11	0	[illegible]	1	[illegible]	3	11	2	9¼	4	[illegible]	6	11	4	10⅔	8	[illegible]
1	0	0	[illegible]	1	[illegible]	4	0	2	10	4	[illegible]	7	0	4	11⅓	8	[illegible]
1	1	0	[illegible]	1	4	4	1	2	[illegible]	5	0	7	1	5	0	8	8
1	2	0	[illegible]	1	5	4	2	2	11⅓	5	1¼	7	2	5	1	8	9¼
1	3	0	[illegible]	1	[illegible]	4	3	3	0	5	[illegible]	7	3	5	[illegible]	8	10½
1	4	0	11	1	[illegible]	4	4	3	0¾	5	[illegible]	7	4	5	[illegible]	8	[illegible]
1	5	1	[illegible]	1	[illegible]	4	5	3	[illegible]	5	[illegible]	7	5	5	3	9	1
1	6	1	[illegible]	1	10	4	6	3	2¼	5	6	7	6	5	3⅔	9	2¼
1	7	1	1	1	11¼	4	7	3	3	5	[illegible]	7	7	5	4⅓	9	[illegible]
1	8	1	2	2	[illegible]	4	8	3	[illegible]	5	[illegible]	7	8	5	5	9	[illegible]
1	9	1	[illegible]	2	1¼	4	9	3	[illegible]	5	[illegible]	7	9	5	5¾	9	6
1	10	1	[illegible]	2	3	4	10	3	5	5	11	7	10	5	[illegible]	9	7
1	11	1	[illegible]	2	4	4	11	3	[illegible]	6	[illegible]	7	11	5	7¼	9	8¼
2	0	1	5	2	[illegible]	5	0	3	[illegible]	6	[illegible]	8	0	5	8	9	[illegible]
2	1	1	[illegible]	2	[illegible]	5	1	3	7	6	[illegible]	8	1	5	[illegible]	9	[illegible]
2	2	1	[illegible]	2	[illegible]	5	2	3	8	6	4	8	2	5	9¼	10	0
2	3	1	7	2	9	5	3	3	[illegible]	6	5	8	3	5	10	10	1
2	4	1	[illegible]	2	[illegible]	5	4	3	[illegible]	6	[illegible]	8	4	5	[illegible]	10	[illegible]
2	5	1	[illegible]	2	[illegible]	5	5	3	10	6	[illegible]	8	5	5	11½	10	[illegible]
2	6	1	9¼	3	[illegible]	5	6	3	[illegible]	6	[illegible]	8	6	6	0	10	5
2	7	1	10	3	2	5	7	3	[illegible]	6	10	8	7	6	[illegible]	10	6
2	8	1	[illegible]	3	3	5	8	4	0	6	[illegible]	8	8	6	[illegible]	10	7¼
2	9	1	[illegible]	3	[illegible]	5	9	4	[illegible]	7	[illegible]	8	9	6	[illegible]	10	[illegible]
2	10	2	0	3	[illegible]	5	10	4	[illegible]	7	[illegible]	8	10	6	3	10	[illegible]
2	11	2	[illegible]	3	6¼	5	11	4	[illegible]	7	3	8	11	6	[illegible]	10	11
3	0	2	1½	3	8	6	0	4	3	7	4	9	0	6	[illegible]	11	[illegible]

EXAMPLE OF THE USE OF THE TABLE.—*Let it be required to find the semi-axis of an ellipse which is the isometrical projection of a circle, the isometrical radius being 2 feet 8 inches.* In one of the columns under isometrical radius, will be found 2 feet 8 inches; and in the same line, in the next column, on the right hand, will be found 1 foot 10⅔ inches, under semi-axis minor; and in the same line further to the right, under semi-axis major, will be found 3 feet 3 inches.

Examples might be introduced to show the applicability of this mode of projection to buildings and the parts of buildings, but its principles are so obvious, and its practice, when these are mastered, so easy, that to multiply examples would be mere surplusage. We shall therefore close this subject with the remark and caution, that although isometrical projection is a valuable addition to the ordinary plan, section, and elevation of the draughtsman, and may be most advantageously used as explanatory of these, it does not give so truthful or pleasing a representation of an object as a proper perspective drawing. It should only be used, therefore, when the object in view is the elucidation or explanation of a subject, and never when pictorial representation alone is intended. Within the limits which we have indicated it is of extended utility, beyond them it is caricature.

INDEX

TO THE CARPENTER AND JOINER'S ASSISTANT;

AND GLOSSARY

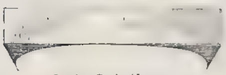
OF TERMS USED IN ARCHITECTURE AND BUILDING.

ABACISCUS.—1. Any flat member.—2. The square compartment of a mosaic pavement.

ABACUS.—A table constituting the upper or crowning member of a column and its capital. It is rectangular in the Tuscan, Doric, and Ionic orders; but in the Corinthian and Composite orders its sides are curved inwards. These curves are called the *arches* of the abacus, and the meeting of the curves its *horns*. The arches are generally decorated with an ornament in the centre of the curve, called the *rose* of the abacus.

The type of the abacus is found in the Grecian Doric order, in which it is a square member. In the Tuscan and Roman Doric it has a moulding and fillet round its upper edge, called the *cymatium*. In the Grecian Ionic the profile of its side is an ovolo or ogee, and in the Roman Ionic an ovolo or ogee with a fillet over; in the Corinthian and Composite orders its mouldings are a cavetto, a fillet, and an ovolo.

Corinthian Abacus



Grecian Doric Abacus

Roman Doric Abacus.

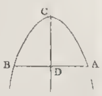
In mediæval architecture the abacus is a strongly marked feature in the earlier styles; but loses this character in the later styles, in which there is no real line of separation between it and the rest of the capital.

ABELE or ABEL TREE.—The white poplar, *Populus alba*. See p. 112.

ABIES. See FIR.

ABSCESSES in Trees detrimental, p. 97.

ABSCISSA.—A part of the diameter, or transverse axis of a conic section, intercepted between the vertex, or some other fixed point, and a semi-ordinate. Thus in the parabolic figure B C A, the part of the axis D C intercepted between the semi-ordinate B D, and the vertex C, is an abscissa.



ABUT, TO.—To adjoin at the end, to be contiguous to; generally contracted to *But*.

ABUTMENT.—1. The solid pier or mound of earth from which an arch springs.—2. *Abutments of a bridge*, the solid extremities on, or against which, the arches rest.

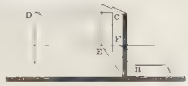
ACACIA.—Properties and uses of, p. 114.

ACANTHUS.—The plant bear's-breech, the

Acanthus.

leaves of which are imitated in the foliage of the Corinthian and Composite capitals.

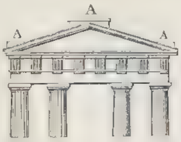
ACCIDENTAL POINT.—In perspective that point in which a right line drawn from the eye of the spectator parallel to another given right line, cuts the plane of the picture. Thus: let A B be the given line, C F E the plane of the picture, D the eye, C D the line parallel to A B, then is C the *accidental point*.



ACER. See MAPLE.

ACOUSTICAL PULPIT, Plate LXXXIII., description of, p. 190.

ACROTER, ACROTERIUM, ACROTERIA.—A small pedestal, placed on the apex or angles of a



Pediment with Acroteria, A A A.

pediment, for the support of a statue or other ornament. The term is also used to denote the pinnacles or other ornaments on the horizontal copings or parapets of buildings, and which are sometimes called *Acroteral Ornaments*.

ADHESION of Surfaces glued together. From Mr. Bevan's experiments it appears that the surfaces of dry ash-wood, cemented by glue newly made, in the dry weather of summer would, after twenty-four hours' standing, adhere with a force of 715 lbs. to the square inch. But when the glue has been frequently melted and the cementing done in wet weather, the adhesive force is reduced to from 300 to 500 lbs. to the square inch. When Scotch fir cut in autumn was tried, the force of adhesion was found to be 562 lbs. to the square inch. Mr. Bevan found the force of cohesion in solid glue to be equal to 4000 lbs. to the square inch, and hence concludes that the application of this substance as a cement is capable of improvement.

ADHESIVE FORCE of Nails and Screws in different kinds of Wood. Mr. Bevan's experiments were attended with the following results:—Small sprigs, 4560 in the pound, and the length of each $\frac{44}{100}$ of an inch, forced into dry Christiania deal to the depth of 0·4 inch, in a direction at right angles to the grain, required 22 lbs. to extract them. Sprigs half an inch long, 3200 in the pound, driven in the same deal to 0·4 in. depth, required 37 lbs. to extract them. Nails 618 in the pound, each nail $1\frac{1}{4}$ inch long, driven 0·5 in. deep, required 58 to extract them. Nails 2 inches long, 130 in the pound, driven 1 inch deep, took 320 lbs. Cast-iron nails, 1 inch long, 380 in the pound, driven 0·5 in., took 72 lbs. Nails 2 inches long, 73 in the pound, driven 1 inch, took 170 lbs.; when driven $1\frac{1}{2}$ inch they took 327 lbs., and when driven 2 inches 530 lbs. The adhesion of nails driven at right angles to the grain was to force of adhesion when driven with the grain, in Christiania deal, 2 to 1, and in green elm as 4 to 3. If the force of adhesion of a nail and Christiania deal be 170, then in similar circumstances the force for green sycamore will be 312, for dry oak 507, for dry beech 667. A common screw $\frac{1}{8}$ of an inch diameter was found to hold with a force three times greater than a nail $2\frac{1}{2}$ inches long, 73 of which weighed a pound, when both entered the same length into the wood.

ADZE (formerly written *Addice*).—A cutting tool used for chopping a surface of timber. It consists of a blade of iron, forming a portion of a cylindrical surface, ground to an edge from the concave side outwards at one end, and having a socket at the other end for the handle, which is set radially. The handle is from 24 to 30 inches long. The weight of the blade is from 2 to 4 lbs. The work is generally laid in a horizontal position, and the instrument held in both hands. The operator, standing in a stooping posture, swings the instrument in a circular path, nearly of the same curvature as the blade. His arms, from the shoulder joint, which forms the centre of motion with the tool, make nearly an inflexible radius, and he thus makes his strokes in a succession of short arcs. The extent of the stroke is gauged by his right thigh, with which his arm comes in contact at each stroke. Standing on his work, the operator, in preparatory work, generally directs the strokes between his feet; but in finer work he directs them under his toe, penetrating the wood with unerring precision, and perfect safety to himself.—*Holtzapffel.*

AERIAL PERSPECTIVE.—That branch of perspective which treats of the representation of the effects of air and atmosphere; and the several gradations, depths, and intensities of light, colour, and shadow, produced by intervening air on objects, as they recede from the eye of the spectator.

AISLE (pronounced *Ile*).—The wing of a building; usually applied to the lateral divisions of a church, which are separated from the central part, called the nave and choir, by pillars and piers. The nave is frequently, though incorrectly, termed the *middle* aisle, and the lateral divisions *side* aisles. See woodcut, CATHEDRAL.

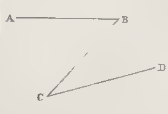
A LA GRECQUE, A LA GREC.—One of the varieties of the fret ornament.

A la Grecque.—Greek Border Ornament

ALBURNUM.—The white and softer part of the wood of exogenous plants; sap-wood. See p. 95.

ALDER, ALDUS.—For description and qualities of, see p. 113.

ALTERNATE ANGLES.—The angles formed by two straight lines, united at their extremities by a third straight line. Thus, the lines A B, C D, united by the line B C, give the alternate angles A B C and B C D. When the angles are equal, the lines A B, C D are parallel.



AMBIT.—1. The perimeter of a figure.—2. The periphery or circumference of a circular body.

AMBO.—A pulpit or reading-desk

AMBRY.—1. A cupboard or closet.—2. In ancient churches a cupboard formed in a recess in the wall, with a door to it, placed by the side of the altar, to contain the sacred utensils.

AMERICAN BENCH CIRCULAR SAW, p. 192.

AMERICAN or WESTERN PLANE, p. 113.

AMERICAN SPRUCE (*Pinus alba*, and *Pinus nigra*).—Properties and uses of, p. 118.

AMPHIPROSTYLE.—Structures having the

Plan of an Amphiprostyle Building.

form of an ancient Greek or Roman rectangular temple, with a prostyle or portico on each of its

ends or fronts, but with no columns on its sides or flanks.

ANAMORPHOSIS.—A term in perspective, denoting a drawing executed in such a manner as to present a distorted image of the object represented; but which, when viewed from a certain point, or reflected by a curved mirror, shows the object in its true proportions.

ANCHOR.—An ornament shaped like an anchor or arrow-head, used in all the orders of architecture. It is applied as an enrichment to the ovolo-echinus or quarter-round, and as it invariably alternates with the egg ornament, the combination is popularly called *egg-and-anchor*, *egg-and-dart*, or *egg-and-tongue*.

ANCON.—An elbow or angle, whence the French term *coin*, a corner; also the English *quoins*, or corner-stones. The corners of walls and beams are sometimes *Ancones*.

ANCONES.—Ornaments cut on the key-stones of arches, or on the sides of door-cases. Called also *Consoles* and *Trusses*.

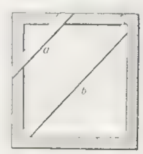
ANGLE.—To make an angle equal to a given angle. Prob. III. p. 5.—To bisect an angle, Prob. IV. p. 5; Prob. V. p. 5.

ANGLE OF REPOSE.—That angle at which one body will just rest on another without slipping. It is called also the *limiting angle of resistance*.

ANGLE-BAR.—The vertical bar at each angle of windows constructed on a polygonal plan.

ANGLE-BEAD, ANGLE-STAFF.—A piece of wood fixed vertically upon the exterior or salient angle of an apartment, to preserve it from injury, and also to serve as a guide by which to float the plaster. It is called also *staff-bead*.

ANGLE-BRACE.—1. A piece of timber fastened at each end to one of the pieces forming the adjacent sides of a system of framing, and subtending the angle formed by their junction. When it is fixed between the opposite angles of a quadrangular frame it is called a *diagonal brace*. It is also called *angle tie* and *diagonal tie*.—2. A boring tool for working in corners and other places where there is not room to swing round the cranked handle of the ordinary brace. It is made of metal, with a pair of bevel pinions, and a winch handle, which revolves at right angles to the axis of the hole to be bored.



ANGLE-BRACKET.—A bracket placed in an interior or exterior angle, and not at right angles with the planes which form it. See ANGLE-BRACKETS, p. 85, and Pl. XIX.

ANGLE-BRACKETS for coves in straight, concave, and convex walls, p. 85, Pl. XIX.

ANGLE-CAPITAL.—An Ionic capital on the flank column of a portico, having volutes on three sides, the exterior volute being placed at an angle of 135° with the plane of the frieze, on front and flank.

ANGLE-IRON. p. 4.

ANGLE RAFTER.—A rafter placed in the line of meeting of the inclined planes of a hip-roof. It is called also *hip-rafter*, and in Scotland *piend-rafter*. See HIP ROOFS, p. 91, and ROOF, p. 135, and Plates XX. and XXI.

ANGLE-RIB.—A curved piece of timber placed in the angle between two adjacent sides of a coved or arched ceiling, so as to range with the common ribs. p. 80.

ANGLES.—Construction of, GEOMETRY, p. 5.

ANGULAR CAPITAL.—A term applied to a comparatively modern variety of the Ionic capital, which has its four sides alike, and all its volutes placed at an angle of 135° with the plane of the frieze.

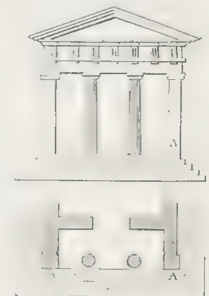
ANGULAR PERSPECTIVE.—A term applied to that kind of perspective in which neither of the sides of the principal object is parallel to the plane of the picture, so that in the representation the horizontal lines of the original object converge to vanishing points. It is called also *oblique perspective*.

ANNULAR VAULT.—A vault springing from two walls, both circular on the plan, the one being concentric to the other.

ANNULATED COLUMNS.—Columns clustered together or joined by rings or bands. They are much used in early English architecture.

ANNULET.—A small moulding, whose horizontal section is circular. It is used indiscriminately as a synonym for list, cincture, fillet, tenia, &c. Correctly, annulets are the fillets or bands which encircle the lower part of the Doric capital, above its neck or trachelium.

ANTÆ.—The pier formed ends of the pteromata or side walls of temples, when they are prolonged beyond the face of the end walls. A term



Portico in Antis. A A, Antæ.

applied to pilasters when they stand opposite a column. A portico *in antis*, is one in which columns stand between antæ.

ANTEFIXÆ.—Upright blocks ornamented on the face, placed at regular intervals on the crowning member of a cornice. These ornaments were originally used to terminate the ends of the covering tiles of the roof.

Antefixæ.

ANTIUM.—In ancient architecture, a porch to a southern door; that to the north was called *Portium*.

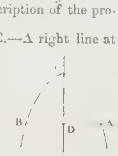
APARTMENT.—1. Used in the singular, is synonymous with room or chamber.—2. The term was formerly used to denote a suite of rooms comprising, at the least, a hall, ante-chamber, chamber, closet, cabinet, and wardrobe, with the necessary conveniences for cooking and the accommodation of domestics.

APERTURES.—The openings in the walls of a building, such as doors and windows.

APOPHYGE, APOLLUSIS, APOPHYSIS.—The parts at the top and bottom of the shaft of a column which spring out to meet the edges of the fillets. The apophyge is usually moulded into a concave sweep or cavetto, and it is often called the *spring* or the *scape*. In French it is termed *congé*.

APPLE TREE, The.—Description of the properties and uses of, p. 114.

APPLICATE-ORDINATE.—A right line at right angles applied to the axis of any conic section, and bounded by the curve. Thus in the figure, the right line B A, at right angles to C D, the axis of the parabola B C A, is termed an *applicate-ordinate*.



APPLICATION of the principles of the resolution of forces to determine the strains on pieces of framing, and the strains transmitted by them, p. 123.

APRON.—1. A platform or flooring of plank at the entrance of a lock, on which the gates are shut.—2. A term used by plumbers in the north of England and in Scotland as synonymous with *flashing*.

APRON-LINING.—The facing of the apron-piece.

APRON PIECE.—A piece of timber fixed into the walls of a staircase, and projecting horizontally, to support the carriage pieces and joisting in the half spaces or landings. It is called also *pitching piece*, p. 196.

APSIS.—A term applied to that part of any building which has a circular or polygonal termination and a vaulted roof. The eastern portion of the church, where the clergy sat and where the altar was placed. It generally had a circular or polygonal termination, and was vaulted over. See woodcut, CATHEDRAL.

APTERAL.—A temple having no columns along its flanks or sides.

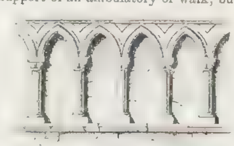
ARABESQUE.—Arabesques or Moresques, a style of ornament composed of representations of a mixture of fruit and flowers, buildings, and other objects. In pure ancient arabesques, such as are found in the Alhambra, no animal representations are used.

Arabesque.

ARÆOSTYLE.—A term applied to a columnar arrangement when the columns are far apart. The interval assigned is four diameters, and it is properly applicable to the Tuscan order only.

ARÆOSYSTYLE.—An arrangement of coupled columns, in which four columns are placed in a space equal to eight diameters and a half. The central intercolumniation is equal to three diameters and a half, and the others on each side to half a diameter.

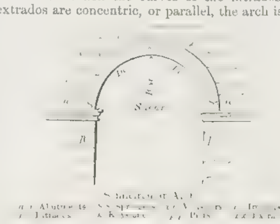
ARCADE.—A series of arches supported on piers or pillars, used generally as the screen and roof support of an ambulatory or walk; but in the



Arcade, Romsey Church, Hampshire.

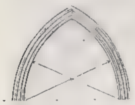
architecture of the middle ages also applied as an ornamental dressing to a wall, as in the figure.

ARCH.—A structure composed of separate inelastic bodies, having the shape of truncated wedges, arranged on a curved line, so as to retain their position by mutual pressure. Arches are usually constructed of stones or of bricks. The separate stones which compose the arch, are called *voussoirs*, or *arch-stones*; the extreme, or lowest voussoirs, are termed *springers*, and the uppermost, or central one, is called the *key-stone*. The under, or concave side of the voussoirs, is called the *intrados*, and the upper, or convex side, the *extrados* of the arch. When the curves of the intrados and extrados are concentric, or parallel, the arch is said



to be *extradosed*. The supports which afford resting and resisting points to the arch, are called *piers* and *abutments*. The upper part of the pier or abutment where the arch rests—technically, where it springs from—is the *impost*. The *span* of an arch, is in circular arches the length of its chord, and generally, the width between the points of its opposite imposts whence it springs. The *rise* of an arch, is the height of the highest point of its intrados above the line of the impost; this point is sometimes called the *under side of the crown*, the highest point of the extrados being the *crown*. Arches are designated in two ways; first, in a general manner, according to their properties, their uses, their position in a building, or their exclusive employment in a particular style of architecture. Thus, there are arches of equilibration, equipollent arches, arches of discharge, askew and reversed arches, and Roman, pointed, and Saracenic arches. Second, they are named specifically, according to the curve their intrados assume, when that curve is the section of any of the geometrical solids, as circular, segmental, cycloidal, elliptical, parabolical, hyperbolical, or catenarian arches; or from the resemblance

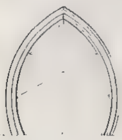
of the whole contour of the curve to some familiar object, as lancet-arch, and horse-shoe arch; or from



Equilateral Arch.

Segmental Arch.

the method used in describing the curve, as three-centred arches, four-centred arches, and the like.



Horse-shoe Arch.

Four-centred or Tudor Arch.

When any arch has one of its imposts higher than the other, it is said to be *rampant*.

ARCH, Equilateral, to draw, p. 28.

ARCH, the Ogee, to draw, p. 30.

ARCH, the Lancet, to draw, p. 29.

ARCH, the Drop, to draw, p. 29.

ARCH, the Four-centred, to draw, p. 29, 30.

ARCH, GOTHIC.—To describe by the intersection of straight lines, p. 30.

ARCH-BRACES in bridge construction, p. 159.

ARCHANGEL TIMBER. See PINUS SYLVESTRIS, p. 116, 117.

ARCHITECTURE.—The art of building; but in a more limited and appropriate sense, the art of constructing houses, bridges, and other buildings for the purposes of civil life. *Architecture* is usually divided into three classes, civil, military, and naval, but when the term architecture is used without a qualifying adjective, civil architecture is always understood.—*Civil architecture* is the art of designing and constructing palaces, houses, churches, bridges, and other edifices for the purposes of civil life; but in a more limited and appropriate sense, it is restricted to such edifices as display symmetrical disposition and fitting proportions of their parts, and are adorned by pillars, entablatures, arches and other contrivances for their embellishment.—*Military architecture* is the art of fortification.—*Naval architecture* is the art of building ships.

ARCHITRAVE.—1. The lower division of an entablature, or that part which rests immediately on the capital of the column. It is sometimes called the *epistylium*. See woodcut, COLUMN.—2. The moulded lining on the faces of the jambs and lintels of a door or window opening, or niche.

ARCHITRAVE-CORNICE.—An entablature consisting of an architrave and cornice only, the frieze being omitted.

ARCHITRAVES.—Illustrations of, Pl. LXIX. p. 182.

ARCHIVOLT.—The architrave or ornamental band of mouldings on the face of an arch following the contour of the intrados.

AREA.—The superficial content of any figure. The method of ascertaining the area of the various geometrical figures will be found under the name of the figure.

ARRIERE-VOUSSURE.—A rear-vault; an arch placed within the opening of a window or door, and of a different form, to increase the light-

Arriere-voussure

way of the window, or to admit of the better opening of the door; it seems also to have served the purpose of an arch of discharge.

ARRIS.—The line in which two straight or curved surfaces of any body, forming an exterior angle, meet each other; an edge.

ARRIS-FILLET.—A triangular piece of wood used to raise the slates of a roof when they abut against the shaft of a chimney or a wall, so as to throw off more effectually the rain from the joining. It is called also a *tilting-fillet*.

ARRIS-GUTTER.—A wooden gutter of the form of a V in section, fixed to the eaves of a building.

ARRIS-WISE.—Tiles or bricks laid diagonally are said to be laid *arris-wise*.

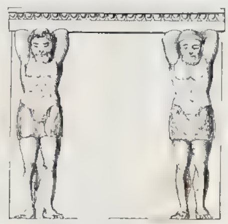
ASH TREE.—Properties and uses of, p. 112.

ASHLERING.—Timber quarterings in garrets for affixing lath to, in forming partitions, to cut off the acute angle made by the meeting of the sloping roof with the floor. They are usually two or three feet high, perpendicular to the floor, and fixed at top to the rafters.

ASTEL.—A board or plank used for partitioning overhead in tunnelling.

ASTRAGAL.—A small moulding, semicircular in its profile. It is frequently ornamented by being carved into the representation of beads or berries.

ATLANTES.—A term applied to figures or half figures of men used in the place of columns or



Atlantes, in the Baths, Pompeii.

pilasters, to support an entablature. They are called also *Telamones*.

ATTACHED COLUMNS.—Those which project three-fourths of their diameter from the wall.

ATTIC BASE.—A peculiar base used by the ancients in the Ionic order or column, and by Palladio and others in the Doric. It consists of an

Attic Base

upper torus, a scotia, and lower torus, with fillets between them

ATTIC ORDER.—An order of small square pillars at the uppermost extremity of a building, above the main cornice. The pillars are never less than a quarter, nor more than one-third of the height of the order over which they are placed.

ATTIC STORY.—The uppermost story of a house when the ceiling is square with the sides; distinguished from *garret*, in which the ceiling, or part of the ceiling, is inclined. Rooms in the attic story are called *attics*.

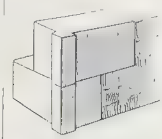
AUGER.—A tool used by carpenters and other artificers in wood, for boring large holes. It consists of an iron blade ending in a steel bit, and having a handle placed at right angles to the blade. Modern augers have a small pointed screw at the extremity, for better entering the wood, and a spiral groove formed in the blade. The lower extremities of the threads of this screw, formed by this groove, are sharpened, to form the bit or cutter; these are called *screw-augers*. Those made with a straight groove or channel are sometimes called *pod-augers*. An ingenious improvement has been recently made by an American. The cutting edges of the lower end of the screw, in place of being parallel to the axis, are rounded off, in imitation of the boring apparatus of the *Teredo navalis*.

AWL.—An iron instrument for piercing small holes. See BRAD and BRAD-AWL.

AXIS.—1. In geometry, the straight line in a plane figure, round which it revolves to generate a solid.—2. Generally, a supposed right line drawn from the centre of one end to the centre of the other, in any figure.—*Axis of a sphere, a cylinder, cone*, &c., is the straight line round which the generating semicircle, rectangle, triangle, &c., revolves.—*Axis-minor, conjugate axis*, or *second axis of a hyperbola and ellipse*, a straight line drawn through the centre perpendicularly to the axis-major or transverse axis.—*Axis-major*, or *transverse axis in the ellipse and hyperbola*, a straight line passing through the two foci and the two principal vertices of the figure. In the ellipse the axis-major is the longest diameter; in the hyperbola it is the shortest.

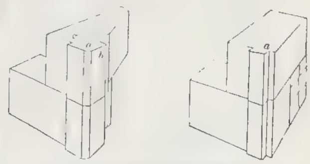
B.

BACK.—The side opposite the face or breast. When a piece of timber is laid in a horizontal or an inclined position, the under side is called the breast, and the upper side the *back*. Thus, we have the back of a hand-rail, the back of a rafter, &c., meaning the upper side.



Quoins with Back-filleted Margins.

BACK-FILLET.—When the margins of a quoin, or those of the jambs of a door or window, project beyond the face of the wall, the return of the projection is called a *back-fillet*, and the margin is said to be *back-filletted*.



Jambs with Back-filleted Margins

a Chamfer b, Reveal. c, Back-fillet. a Back-fillet.

BACK-FLAPS. p. 188.

BACK-LINING.—The piece of a sash-frame parallel to the pulley piece and next to the jamb. See p. 187.

BACKER.—A term used to denote a narrow slate laid on the back of a broad, square-headed slate, where the slates begin to diminish in width.

BACKING OF THE HIP, p. 91.

BADIGEON.—A mixture of plaster and free-stone ground together and sifted, used by statuaries to fill the small holes and repair the defects of the stones of which they make their statues.

BAGUETTE.—An astragal or bead.

BALANCE-BEAM.—A long beam attached to the gate of a lock, serving to open and shut it.

BALCONY.—A projection in front of a house; a frame of wood, iron, or stone, supported by pillars, columns, or consoles, and encompassed with a balustrade railing or parapet. Balconies are common before windows.

BALECTION-MOULDINGS. See BOLECTION.

BALK.—A piece of timber from 4 to 10 inches square.

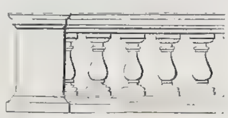
BALL-FLOWER.—An ornament resembling a ball inclosed in a circular flower, the three petals of which form a cup round it. The ball-flower ornament is usually found inserted in a hollow moulding, and may be considered as one of the characteristics of the Decorated style.

Ball-flower.

BALTIC TIMBER.—Description and uses of, p. 115–118.

BALUSTER.—A small column having a swelling in the middle and mouldings to form a base and capital, used in balustrades. The lateral part of the Ionic capital is also called the *baluster*.

BALUSTRADE.—A row of balusters set on a



Balustrade

continuous plinth, and surmounted by a cap or rail, serving as a fence for altars, balconies, terraces,

steps, staircases, tops of buildings, &c. Balustrades are sometimes used solely as ornaments.

BAMBOO.—Multifarious uses of, p. 94.

BAND.—In classic architecture, any flat member with small projection. In mediæval architecture, the round mouldings or suite of mouldings which girds the middle of the shafts in the early English style.

BANDELET, BANDLET.—A narrow band.

BANDING PLANE.—A plane intended for cutting out grooves and inlaying strings and bands in straight and circular work.

BANISTER.—A corruption of *baluster*.

BANKER.—A bench upon which masons place the stones about to be hewn. In Scotland termed a *siege*.

BAR or BARRED DOOR.—The Scottish synonym for *ledged door;* a door formed of narrow deals joined by grooving and tongueing or by rebating, and secured by bars or ledges nailed across the back.

BAR-POSTS.—Posts driven into the ground to form the two sides of a field gateway. They have holes corresponding to each other, into which bars are inserted to form the fence.

BARGE-BOARDS, called also GABLE-BOARDS. The raking boards at the gable of a building, placed to cover the ends of the roof timbers when they project beyond the walls. They are sometimes called *verge-boards*, and are variously ornamented. See illustration, Plate XLVII., TIMBER-HOUSES; Figs. 3 and 4, Gable boards.

BARGE-COUPLES.—The exterior couples of a roof which project beyond the gable.

BARGE-COURSE. The course of tiles which covers and overhangs the gable-wall of a building, and is made up below with mortar; also, a coping to a wall formed of a course of bricks set on edge.

BASE. -The bottom of anything, considered as its support or that whereon it stands or rests. The base of a pillar or column is that part which lies between the top of the pedestal and the bottom of the shaft; but where there is no pedestal it is the moulding or series of mouldings between the bottom of the shaft and the plinth; and in the Grecian Doric, the steps on which the column stands form its base. The lowest part of a pedestal, and the plain or moulded fittings which surround the bottom of a wall next the floor, are also termed the base of the pedestal and apartment respectively.

BASE-LINE.—In perspective, the common section of the picture and the horizontal plane, p. 228.

BASE-MOULDINGS. -The mouldings immediately above the plinth of a wall, pillar, or pedestal.

BASEMENT.—1. The ground floor on which the order or columns which decorate the principal story are placed.—2. A story below the level of the street.

BASIL.—The slope or angle of the cutting part of a tool or instrument, such as a chisel or plane. All edge tools may be regarded as wedges formed by the meeting of two straight or curved surfaces, or of a straight and curvilinear surface, at angles varying from 20° to 12°. Occasionally the tool is ground with two basils, as in the case of the hatchet, the turner's chisel, and some others.—The angle of the basil in cutting tools depends on the hardness or softness of the material to be operated upon, and on the direction of its fibres. Mr. Holtzapfell classifies cutting tools in the three following groups:—1st. Paring tools, with their edges the angles of which do not exceed 60°; one plane forming the edge being nearly coincident with the work produced. These tools remove the fibres principally in the direction of their length. 2d. Scraping tools with thick edges, varying from 60° to 120°, the planes of the edges forming nearly equal angles with the surfaces produced. Such tools remove the fibres in all directions with nearly equal facility, producing fine dust like shavings, by acting superficially. 3d. Shearing or separating tools, with edges from 60° to 90°, generally duplex, and then applied on opposite sides of the substance to be operated upon. One plane of each tool, or of the single tool, is coincident with the plane produced.—*Holtzapfell* chiefly. See CUTTING TOOLS, and particular description under the name of each separate tool.

BASKET-HANDLE ARCH (Fr. *anse de panier*).—Any arch whose vertical height is less than half its horizontal diameter; consequently the term includes all surbased and semi-elliptic arches.

BASS RELIEF. See RELIEF.

BASSOOLAH.—The Indian adze. In place of being circular, like the European adze, this is formed at a direct angle of 45° to 50°. Its handle is very short, and it is used with great precision by the nearly exclusive motion of the elbow joint. In different districts the instrument varies in weight, and in the angle which the cutting face forms with the line of the handle. The average weight, however, may be stated at 11 lbs. 12 oz., and the length of the handle 12 or 13 inches. In using, it is grasped so near the blade that the fore finger rests on the metal, the thumb nearly on the back of the handle, the other fingers grasping the front of it, with their nails approaching the ball of the thumb. When the head of the instrument is made about 2 lbs. weight, it is a very handy tool for blocking out hard or soft woods.—*Holtzapfell.*

BASTON, BATON, BATOON.—Another name for the *torus*, or round moulding in the base of a column, or otherwise applied. See woodcut, COLUMN.

BATTEN.—A piece of timber from $1\frac{1}{2}$ inch to 7 inches broad, and $\frac{1}{2}$ inch to $2\frac{1}{2}$ inches thick. The battens of commerce are 7 inches by $2\frac{1}{2}$ inches.

BATTEN DOOR.—A ledged door or barred door.

BATTENING.—Narrow battens fixed to a wall, to which the laths for plastering are nailed. They are attached to the wall, either by nailing to bond-timbers built in for the purpose, or fixed directly to the wall by holdfasts of wrought iron; and they should always be so fixed when crossing flues.

BATTER.—To incline from the perpendicular. Thus a wall is said to batter when it recedes as it rises.

BATTLEMENT.—A parapet of a building provided with openings or embrasures, or the embrasures themselves. The portions of wall which separate the embrasures are called *merlons*.

BAULK.—A piece of whole timber, being the squared trunk of any of the trees usually employed in buildings.—The tie-beam of a common couple roof is called a *baulk* in Scotland.

BAY.—A term applied in architecture without much precision.—1. Any opening in a wall left for the insertion of a door or window.—2. Any distinct recess in a building.—3. The quadrangular space between the principal divisions of a groined roof, over which a pair of diagonal ribs extend, and rest on the four angles.—4. The horizontal space between two principals.—5. The division of a building comprised between two buttresses.—6. The part of a window included between two mullions, called also *day* or *light*.—7. In a barn, a low inclosed space for depositing straw or hay; or the space between the thrashing-floor and the end of the barn. If a barn consists of a floor and two heads, where corn is laid, it is called a *barn of two bays.*

BAY-WINDOW.—A projecting window, rising from the ground or basement on a semi-octagonal or some other polygonal plan, but generally understood to be straight-sided. When a projecting window is circular in its plan, it is a *bow-window*; when it is supported on a bracket or corbel, and is circular or polygonal, it is an *oriel*. These distinctions are too little attended to in practice, the terms being often used synonymously.

BEAD.—A round moulding of very frequent use, called also *baguette.*—A series of beads parallel to and in contact with each other is called a *reed*.—In joinery the bead is of constant occurrence, and is formed, or *run*, as the term is, on the edges of boards which have to be jointed together, and thus they serve to admit of and yet to disguise any shrinkage which the wood may undergo. The bead is also much used in framed work. When it is flush with the face of the work it is called a *quirk*-bead; when it is raised, a *cock*-bead. See p. 183, 184, JOINERY.

BEAD-BUTT. JOINERY, p. 185.

BEAD-FLUSH. JOINERY, p. 185.

BEAK.—Synonymous with *bird's mouth* (which see).

BEAM. See GIRDER.

BEAM-COMPASS.—An instrument used in describing large circles. It consists of a wooden or brass beam, having sliding sockets, with steel and pencil or ink points. See description and use of, p. 34.

BEAM-FILLING.—Filling in between timbers with masonry or brick-work.

BEARERS, in staircases, p. 196.

BEARING.—The space between the two fixed extremes of a piece of timber; the unsupported part of a piece of timber; also, the length of the part that rests on the supports.

BED-MOULDING.—Properly those members of a cornice which lie below the corona.

BEECH TREE. -For description of properties and uses, see p. 111, 112.

BEETLE. -A heavy wooden maul or hammer.

BELECTION. -See BALECTION and BOLECTION.

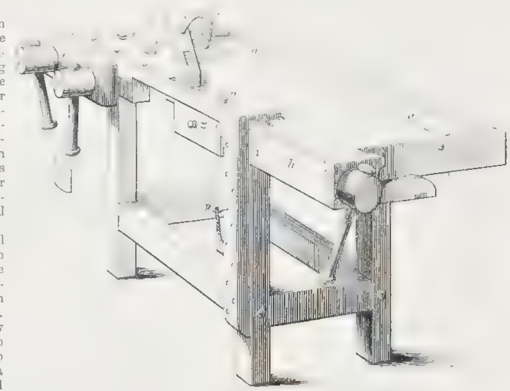
BELFRY.—That part of a steeple or other building in which a bell or bells are hung, and more particularly the timber work for sustaining the bell.

BELL.—The body of a Corinthian or Composite capital, supposing the foliage stripped off.

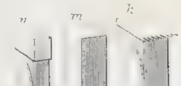
BELL-GABLE.—In small Gothic churches and chapels, a kind of turret placed on the apex of a gable, at the west end, and carrying a bell or sometimes two bells.

BELL-ROOF.—A roof shaped like a bell, its vertical section being a curve of contrary flexure. Plate XXXV. Fig. 1, No. 1.

BENCH.—A strong table on which carpenters, joiners, cabinetmakers, and other artisans prepare their work. In respect of those required by the cabinetmaker, joiner, and carpenter, a few remarks may be made. These benches are made in various ways, from a few rough boards nailed together, to very complete structures, with various means and appliances for holding and fastening the work while being operated on. A cabinetmaker's bench, of the most complete kind, is shown in the figure. The framing is connected by screw-bolts and nuts. The top surface is a thick plank planed very true. It has a trough at *a* to receive small tools, and a drawer at *z* Two side-screws *c d*, which, with the chop *e*, constitute a vice for fixing work. An end-screw *g*, and sliding-piece *h*, form another vice for thin works which require to be held at right angles to the position of the other chop *e*; but its chief use is to hold work by the two ends. Work, when laid on the top of the bench, is steadied by the iron bench-hook *k*, which slides in a mortise in the top, and has teeth at the end which catches the wood. When work would be injured by the bench hook, the stop *m*, sliding stiffly in a square mortise in the bench-top, serves to stay it. The stop and bench-hook are shown separately above, drawn to a much



Cabinetmaker's Bench.



Stop.

larger scale. There are several square holes along the front of the top, also, at distances apart from each other equal to the motion of the sliding-piece *h*, which has a similar hole. In these bench-holes the iron stop *n* is inserted, and a similar stop is also inserted in the hole in *h*. Thus, any piece of wood whose length does not exceed the distance between the end-hole of the bench and the stop in *h* when it is drawn out to the full extent of its range, may be secured. The face of the stop *n* is slightly roughened. A holdfast *o*, sliding loosely in a mortise, is used in holding square pieces of work on the bench. It is fixed by driving on the top, and released by driving on the back. At *p* is a pin, which is placed in any of the holes shown in the piece in which it is fixed, to support the end of long pieces, which are held by the screws *c d*, at their other extremity. Various improvements in the bench-hooks, stops, and holdfasts have been from time to time suggested, such as making them work by screws; but being in their simple form sufficiently manageable, and the improvements being more expensive, they have not obtained general use.—The carpenter's bench is composed of a platform or top, supported on strong framing. It is furnished with a bench-hook at the left-hand end; at which end also the side-board has the screw and screw-cheek, together forming the vice or bench-screw. The side-board and right-hand leg of the bench are pierced with holes, into any one of which a pin is inserted, to hold up the end of any long piece of work clamped in the bench-screw. The length of the bench may be 10 to 12 feet, the breadth 2 feet 6 inches, the height about 2 feet 8 inches. The legs should be 3½ inches square, well braced; front top-board should be 2 inches thick; the further boards may be 1½ inch. These two benches may be regarded as the opposite extremes of the scale, and between them may be many varieties both in size and in the number of the fittings, as inclination or the necessities of the workman may dictate.

BENCH-HOOK, Bench-Holdfast. See previous word.

BENCH-PLANES.—The following planes, used for surfaces by the joiner, are usually called bench-planes:—

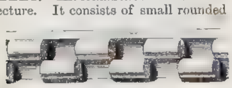
	Length.	Width.	Width of Iron
Jack Plane, . .	12 to 17 ins.	2½ to 3 ins.	2 to 2¼ ins
Trying Plane, .	20 to 22 ,,	3¼ to 3⅜ ,,	2[illegible] to 2½ ,,
Long Plane, . .	24 to 26 ,,	3⅜ ,,	2[illegible] ,,
Jointer, ...	28 to 30 ,,	3¾ ,,	2[illegible] ,,
Smoothing Plane,	6½ to 8 ,,	2⅝ to 3⅛ ,,	1¾ to 2⅜ ,,
Block Plane, . .	12 ,,		
Compass Plane, .	6½ to 8 ,,	2⅝ to 3⅛ ,,	1¾ to 2⅜ ,,

BENDING TIMBER.—Various methods described, p. 102; Colonel Emy's method, p. 103; Mr. T. Blanchard's process, p. 103.

BEVEL.—An instrument for drawing angles. It consists of two limbs jointed together, one called the *stock*, and the other the *blade*, which is moveable on a pivot at the joint, so that it may be adjusted to include any angle between it and the stock.

BEVEL-TOOLS.—Tools used in turning hard woods. They are in pairs, and their cutting edges are bevelled off right and left.

BILLET.—An ornament much used in Norman architecture. It consists of small rounded billets,



Billet-moulding.

like an imitation of small pieces of stick, placed in a hollow moulding at intervals apart generally equal to their length.

BILLS.—1. The ends of compasses.—2. Knee-timbers.

BINDING-JOISTS.—Beams in framed floors which support the bridging-joists above and the ceiling-joists below. See Floors, Plate XLII., and description, p. 150.—*Binding-joists.* Rule for finding the strength of, p. 154.

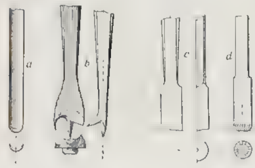
BINDING-RAFTERS.—The same as *Purlins.*

BIORNBURG TIMBER. See Pinus sylvestris, p. 116, 117.

BIRCH.—The common birch, *Betula alba;* the mahogany birch of America, *Betula lenta;* tall or yellow birch, *Betula excelsa;* black birch, *Betula nigra.* For description of qualities and uses of the varieties generally used, see p. 113.

BIRD'S MOUTH.—An interior angle or notch cut across the grain at the extremity of a piece of timber, for its reception on the edge of another piece.

BIT.—1. The cutting part of a plane.—2. A name common to all those exchangeable boring tools for wood applied by means of the crank-formed handle known as the carpenter's brace. The similar tools used for metal, and applied by the drill-bow, ratchet, brace, lathe, or drilling-machine, are termed *drills* or *drill-bits.* The distinction, however, is not uniformly maintained: very frequently all those small revolving borers which admit of being exchanged in their holders or stocks, are included under the name of *bits.* The variety is, therefore, very great, and the particular names used to designate them are derived, in most cases, from their forms and the purposes for which they are employed. For wood, the typical form is the *shell-bit* (fig. *a*), which is

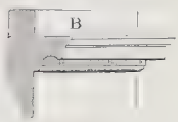


shaped like a gouge, with the piercing end sharpened to a semicircular edge for shearing the fibres round the circumference of the hole. When large, it is termed a *gouge-bit*, and when small, a *quill-bit.* Sometimes the piercing end is drawn to a radial point, and it is then known as the *spoon-bit*—of which the *cooper's dowel-bit* and the *table* or *furniture bit* are examples. Occasionally the end is bent into a semicircular form horizontally, and it then becomes the *duck-nose bit.* The *centre-bit* (fig. *b*), is another typical form, of which there are many modifications. The end is flat, and provided with a centre-point or *pin*, filed triangularly, and which serves as a guide for position; a shearing edge or *nicker* serving to cut the fibres round the margin of the hole, and a broad chisel-edge or *cutter* to pare away and remove the wood within the circle defined by the nicker. The *plug centre-bit*, used chiefly for making countersinks for cylinder-headed screws; the *button-tool*, which retains only the centre pin and nicker, and is used for cutting out discs of leather and the like; the *flute-drill*, the *cup key tool*, the *wine-cooper's bit*, are all modifications of this borer, suited to special kinds of work. The *half-round bit* (fig. *c*), is employed for enlarging holes in metal, and is usually fixed in the lathe or vertically. The cutting end is ground with an incline to the right angle, both horizontally and vertically, three to six degrees, according to the hardness of the material to be bored. The *rose-bit* (fig. *d*), is cylindrical, and terminates in a truncated cone, the oblique surface of which is cut into teeth like the rose-countersink, of which it is a modification. It is also used for enlarging holes of considerable depth in metals and hard woods.

BLACK WALNUT TREE.—Properties and uses of, p. 111.

BLANK DOOR, Blank Window.—A recess in a wall, made to appear like a door or window as the case may be.

BLOCKING COURSE.—The course of stones



B Blocking-course.

or bricks erected on the upper part of a cornice to make a termination.

BLOCKINGS.—Small pieces of wood fitted to the interior angle of two meeting boards, and glued there to strengthen the joint, as *m m m*, Fig. 1, Nos. 3 and 4, Plate LXXII.

BOARD.—A piece of timber sawed thin, and of considerable length and breadth as compared with its thickness.

BOARDING-JOISTS.—The bridging-joists to which the floor boarding is nailed.

BOASTING or Scabbling.—In stone cutting, an operation performed with a chisel and mallet. The chisel is about 2 inches broad, and its cutting edge ground quite sharp. With this tool, impelled by the mallet, the ridges left between the grooves formed in brotching are worked off, till the whole surface is reduced to the plane of the draughts. The workman commences at the angle of the stone most remote from him on his right hand, and runs the chisel draughts diagonally towards his left hand, or he commences at the angle nearest to him on his right hand.

BODY of a Niche.—The vertical surface, whatever be its horizontal surface.—*Body range* of a groin. The larger of the two vaults, by the intersection of which the groin is formed, p. 78.—*Body* of a room. The main part of an apartment, independent of any recesses.

BOLECTION-MOULDINGS.—Mouldings in framed work which project beyond the surface of the framing. Called also *balection* and *belection.* See p. 185.

BOLSTERS of the Ionic Capital.—1. The lateral part which joins two volutes.—2. Same as *balusters* (which see).

BOLT.—A cylindrical piece of wrought iron for fastening together the parts of framing or machinery. Mr. Farey gives the following rule for proportioning the size of the bolt to the strain to which it is to be exposed, viz.: Divide the given strain in lbs. by 2200, and the square root of the quotient is the proper diameter of the pin of the bolt.

BOND, in masonry and brickwork, signifies that disposition of the materials by which the joints of one course are covered by the stones or bricks of the next course horizontally and vertically, so as to make the whole aggregate act together, and be mutually dependent on each other. See also English Bond and Flemish Bond.

BOND-TIMBER.—Timbers placed in horizontal tiers at certain intervals in the walls of buildings for attaching battens, laths, and other finishings of wood.

BONING; in Scotland termed Borning.—The act of judging of a plane surface, or of setting objects in the same plane or line by the eye.

BORING TOOLS. See Auger, Awl, Bit, Broach, &c.

BOSS.—An ornament placed at the intersection

Boss, York Cathedral.

of the ribs of groined or cross-vaulted roofs. It is frequently richly sculptured.

BOTTOM PANEL.—The lowest panel in framed work. See p. 186.

BOTTOM RAIL.—A term used to denote the lowest rail in a piece of framed work. See p. 186.

BOULTINE.—A convex moulding, the contour of whose section is a quadrant. It is generally used below the abacus of the Tuscan and Doric capitals. It is called more commonly *ovolo* or *quarter-round.* See Plate LXIII., Mouldings.

BOW-COMPASSES.—Different kinds of, and instructions how to use, see p. 33.

BOW-SAW; called also Frame-Saw and Sweep-Saw.—It is used for cutting curves. The frame of this saw consists of a central rod or stretcher, to which are mortised two end pieces that have a slight motion of rotation on the stretcher. These end pieces are each adapted at one extremity to receive the saw-blade, and the other ends are connected by a coil of string, in the middle of which is a short lever. On turning round the lever, the string is twisted, and thereby shortened. It thus draws together those ends of the cross pieces to which it is attached, and separates the opposite ends, by which means the saw is stretched. In using the bow-saw, the work is usually fixed vertically, and the saw worked horizontally; but the frame is placed at all angles, so as to clear the work.

BOWTEL.—The shaft of a clustered pillar, or any plain round moulding.

BOX TREE.—For properties and uses, see p. 115.

BOXED SHUTTERS.—Those which fold back into a box or case.

BOXINGS of a Window.—The cases, one on each side of the window, and opposite to each other, into which the shutters are folded. The shutters in this case are termed *boxed-shutters.* See illustration, p. 188, and Plate LXXVIII., Window-Finishings.

BRACE.—A piece of timber in any system of framing extending across the angle between two other pieces at right angles. See action of braces

and counterbraces, BRIDGES, p. 159, 166; and illustration of braces in framing timber houses, Fig. 470, p. 157.

BRACE AND BIT.—The brace is an instrument made of wood or iron. It consists of a cranked shaft, having at its one end a socket, called the *pad*, to receive the bits or boring tools, and at the other a swivelled head or shield, which, when the instrument is used horizontally, is pressed forward by the workman's breast, and when vertically, by his left hand, which is commonly placed against his forehead. See BIT.

BRACKET.—A small support against a wall for a figure, clock, &c. Brackets, in joinery, are either cut out of deal or framed with three pieces of timber, viz., a vertical piece attached to the wall, a horizontal piece attached to the shelf to be supported, and an angle brace framed between the horizontal and vertical pieces.

BRACKETED STAIRS, p. 196.

BRACKETS, Diminishing and Enlarging, p. 201.

BRAD.—A particular kind of nail, used in floors or other work where it is deemed proper to drive nails entirely into the wood. To this end it is made without a broad head or shoulder on the shank.

BRAD-AWL.—An awl used to make holes for brads.

BRANCHED WORK.—The carved and sculptured ornaments in panels, friezes, &c., composed of leaves and branches.

BRANDERING.—Covering the under side of joists with battens about 1 inch square in the section, and 12 to 14 inches apart, to nail the laths to, in order to secure a better key for the plaster of a ceiling. See p. 154.

BRANDISHING OR BRATTISHING.—A crest, battlement, or other parapet.

BRANDRETH.—A fence or rail round the opening of a well.

BREAK.—A recess; also, any projection from the general surface of a wall or building.

BREAKING-JOINT.—That disposition of joints by which the occurrence of two contiguous joints in the same straight line is avoided.

BREAST-LINING, p. 188.

BRESSUMMER OR BREASTSUMMER.—A summer or beam used in the face or breast of a wall, as a lintel to support a superincumbent wall. Its use is generally restricted to a beam used as a lintel in an external wall, such as over the wide openings of shop fronts. See TIMBER HOUSES, p. 154.

BRICK-NOGGING. Brick-work carried up and filled in between timber framing.

BRICK-TRIMMER.—A brick arch abutting against the wood trimming joist in front of a fire-place, and used to support the hearth. See FLOORS, p. 151.

BRICK-WORK is valued by the cubic yard, and also by the rod. A rod of brick-work is a quantity of 272¼ superficial feet, of the thickness of a brick and a half, or 13½ inches. The quarter of a foot is generally disregarded, and the round number 272 feet is reckoned a rod. Hence a rod of brick-work is 306 cubic feet, and contains 4500 bricks, allowing for waste.

BRIDGE.—Any structure of wood, stone, or iron raised over a river, pond, lake, or hollow of any kind, to support a roadway for the passage of men, vehicles, &c. Among rude nations, bridges are sometimes formed of other materials than those enumerated; and sometimes they are formed of boats, or logs of wood lying on the water, fastened together, covered with planks, and called floating bridges. A bridge over a marsh is made of logs or other materials laid upon the surface of the earth.—In *suspension* or *chain bridges*, the flooring, or main body of the bridge, is supported on strong iron chains or rods, hanging in the form of an inverted arch from one point of support to another. The points of support are the tops of strong pillars or towers, erected for the purpose at each extremity of the bridge. Over these pillars the chains pass, and are attached beyond them to rocks or massive frames of iron firmly secured under ground. The flooring is connected with the chains by means of strong upright iron rods.—A *draw-bridge* is one which is made with hinges, and may be raised or opened. Such bridges are constructed in fortifications, to hinder the passage of a ditch or moat; and over rivers, dock-entrances, and canals, that the passage of vessels may not be interrupted.—A *flying-bridge* is made of pontoons, light boats, hollow beams, empty casks, or the like. It is made, as occasion requires, for the passage of armies. A flying-bridge is also constructed in such a manner as to move from one side of a river to the other. It consists of a boat secured to a long cable, made fast in the middle of the river by an anchor, and by the action of the helm it can be made to swing from one bank to the other

BRIDGE.—Classification of the usual forms of bridge trusses, p. 161.

BRIDGE-BOARD OR NOTCH-BOARD.—A board into which the ends of wooden steps are fastened See p. 195, Fig. 512.

BRIDGE GUTTER.—Gutters formed of boards covered with lead, supported on wooden bearers.

BRIDGE OVER.—A piece of timber which is laid over parallel lines of support, crossing them transversely, is said to bridge over them. Thus, in flooring, the upper joists to which the boards are attached bridge over the binding-joists which extend transversely beneath them, and they are therefore called bridging joists.

BRIDGES.—Consideration of the forces which act on framed trusses as applied in the construction of, p. 158.

BRIDGES.—Mr. Haupt's rules for calculating the strains on the different pieces composing the truss. See p. 160.

BRIDGES, TIMBER.—Theory of the construction, of, p. 158.

BRIDGES illustrated and described

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Skew-bridge at Portobello, on the North British Railway, . .	LV.	170
Bridge over the Tweed at Mertoun,	LVI.	171

BRIDGING-FLOORS.—Those in which bridging-joists are used. See p. 150.

BRIDGING-JOISTS.—The upper joists in a framed floor, to which the flooring boards are nailed. See BRIDGE OVER FLOORS, p. 150; and illustration, Plate XLII.

BRIDGING-JOISTS.—Rules for calculating the strength of, p. 154.

BRIDGINGS.—Pieces of wood placed between two beams or other timbers, to prevent their approaching each other. More generally termed *straining* or *strutting pieces*.

BRINGING UP, OR CARRYING UP, signifies the same as *building up*.

BROACH.—A general name for all tapered boring bits or drills. Those for wood are fluted like the shell-bit, but tapered towards the point; but those for metal are solid, and usually three, four, or six sided. Their usual forms are shown in the annexed figures. Broaches are also known as *wideners* and *rimers*. Fig. *a* is an example of the broach or rimer for wood, and fig. *b* of those for metal.

BROACH.—An old English term for a spire; still in use in the north of England, as *Hesslebroach*, &c.; and in some other parts of the country, as in Leicestershire, it is used to denote a spire springing from the tower without any intermediate parapet.

BROAD.—An edge tool for turning soft wood. The edge of the broad is at right angles to the handle, and the blade is either square or triangular. The triangular broad is used principally for turning large pieces the plank way of the grain.

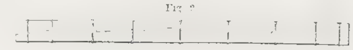
BUCRANIA.—Sculptured ornaments representing ox-skulls adorned with wreaths or other ornaments, which were employed to decorate the frieze of the entablature, in the Ionic and Corinthian orders of architecture.

BUILDING.—A fabric or edifice constructed for use or convenience; as a house, a church, a shop.

BUILDING A BEAM is accomplished in the simplest manner, by laying the flitches above each other, and bolting or hooping them together. The sliding of the pieces is prevented by the insertion of keys. This mode is shown in fig. 1. Another method is to table or indent the surfaces of the pieces together, and secure with hoops. Fig. 2 represents this mode. In the first method the practical rule to find the size of the keys:—To the depth of the beam in inches add three-eighths of the depth, and divide the sum by the number of keys to be used; the quotient will be the thickness of each key, and their breadth should be twice their thickness. In the second method the sum of the depth of the indents should be equal to two-thirds of the depth of the beam. The indents should be made to form abutments to the pressure. See p. 148.

Fig. 1

Fig. 2



Building a Beam

BUILT BEAM.—One composed of several pieces.

BULL-NOSED BRICKS.—Those with one of their vertical angles rounded.

BULLER NAILS.—Round-headed nails with short shanks, turned and lackered; used chiefly for the hangings of rooms.

BULLET WOOD.—A wood of a greenish hazel colour, close and hard, the produce of the Virgin Isles, West Indies. It resembles green-heart.

BULL'S-EYE.—A small circular or elliptical window.

BULL'S-NOSE.—The external angle of a polygon, or any obtuse angle.

BUTMENTS. ABUTMENTS.

BUTT END OF TIMBER.—That which is nearest the root of the tree.

BUTT-HINGES.—Those which are placed on the edges of doors, &c., with their knuckle on the side on which the door opens See HINGING, p. 180, and Plates LXXXIV.-LXXXVI.

BUTT-JOINT.—That formed by two pieces of timber united endways.

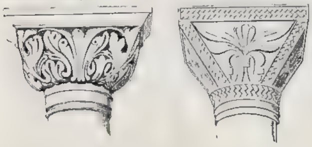
BUTTRESS.—1. A prop.—2. A projection from a wall to impart additional strength and support.—3. A wall or abutment built archwise, serving to support another wall on the outside, when very high or loaded with a heavy superstructure. Buttresses are much employed in Norman architecture, and in all the styles of the Gothic. In the Norman they are generally of considerable breadth and very small projection, while in the Pointed styles their projection is usually much greater than their breadth. They are almost invariably divided into stages with sloping copings: the slope of the copings being progressively increased in each stage of the ascent. By this means the higher copings present to the eye of a spectator nearly as great a

Buttress, Winchester Cathedral.

surface as the lower ones, as they do not become so much fore-shortened as they otherwise would do.

BYZANTINE ARCHITECTURE.—A style of architecture developed in the Byzantine Empire about A.D. 300, and which, under various modifications, continued in use till the final conquest of that empire by the Turks in A.D. 1453. It spread so widely, and was so thoroughly identified with all middle-age art, that its influence even in Italy did not wholly decline before the fifteenth century. Its ruling principle is incrustation, the incrustation of brick with more precious materials; large spaces are left void of bold architectural features, to be rendered interesting merely by surface ornament or sculpture. It depended much on colour for its effect, and with this intent, mosaics wrought on grounds of gold or of positive colour, are profusely employed. The leading forms which pervade the Byzantine are the round arch, the dome, the circle,

Fig 1 Fig 2.



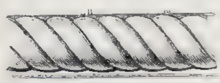
Byzantine Capitals.

Fig 1 From the Apse of Murano. Fig. 2 From the Casa Loredan, Venice.

and the cross. The capitals of the pillars are of endless variety, and full of invention; while some are founded on the Greek-Corinthian, many approach in character to those of the Norman; and so varied are their decorations, that frequently no two sides of the same capital are alike. Both the Norman and the Lombardic styles may be considered as varieties of the Byzantine, and all of these are comprised under the term *Romanesque*, which comprehends the round-arch style of middle-age art, as distinguished from the Saracenic and the Gothic, which are pointed-arch styles. The mosque of St. Sophia, Constantinople, and the church of St. Mark's, Venice, are prominent examples of Byzantine architecture.

C.

CABLE-MOULDING.—A cylindrical moulding inserted in a flute so as partly to fill it. In



Cable-moulding.

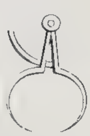
mediæval architecture the cable is a moulding of the torus kind, carved in imitation of a rope.

CABLING.—The filling of flutes with cable mouldings, or the cables themselves, whether disposed in flutes or without them.

CAISSON.—A sunken panel in a ceiling or soffit. See COFFER, which is the proper term.

CAISSONS OF AN ELLIPSOIDAL VAULT.—To determine the, p. 83.

CALIBER, CALIBRE, CALIPER COMPASSES.—Compasses made with arched legs, to take the dimensions of the exterior diameter of round bodies; and also compasses made with straight legs, with their points retracted, used to measure the interior diameter or bore of a cylinder.



Caliber Compasses.

CAMBER.—A curve or arch.—*Cambered beam*, a beam bent or cut in a curve like an arch.

CAMP-CEILING.—1. The interior of a truncated pyramid.—2. The ceiling of an attic room where all the sides are equally inclined from the wall to meet the horizontal part in the centre.

CAMPANILE.—A clock or bell tower. The term is more especially applied to detached buildings in some parts of Italy, erected for the purpose of containing bells, and to towers of similar design erected elsewhere.

CANADIAN TIMBER, p. 118.

CANAL.—The same as *flute*.—*Canal of the larmier*, the hollow made in the soffit or under side of a cornice.—*Canal of a volute*, a channel in the face of the circumvolutions of the Ionic capital, inclosed by a list or fillet.

CANKERS in trees, p. 97.

CANOPY.—1. A decoration serving as a hood or cover suspended over an altar, throne, chair of state, pulpit, and the like.—2. The ornamental projecting head of a niche or tabernacle.—3. The label moulding or drip-stone surrounding the head of a door or window when ornamented.

CANT, *v.*—To truncate or cut off the external angle formed by the meeting of two planes. Also, to turn over anything on its angle.

CANT, *n.*—An external or salient angle.

CANT-MOULDING.—Any moulding with a bevelled face.

CANTED COLUMN.—A column polygonal in section.

CANTILEVER, CANTALIVER.—Wooden or iron blocks framed into the side of a house under

Cantilever.

the eaves, and projecting so as to carry a cornice, a projecting eave, or other moulding. Cantilevers serve the same end as modillions; but the use of the latter is confined to regular architecture, while the former are in general and trivial use.

CAP.—The congeries of mouldings which forms the head of a pier or pilaster. In joinery, the uppermost of any assemblage of parts.

CAPITAL.—The uppermost part of a column, pillar, or pilaster, serving as the head or crowning, and placed immediately over the shaft and under the entablature. In classic architecture the different orders have their respective capitals; but in Egyptian, Indian, Byzantine, and Gothic architecture they are endlessly diversified.

CAPPING PIECES.—A general name for horizontal timbers which extend over upright posts, and into which the posts are framed. See p. 156.

CARACOLE.—A spiral staircase.

CARCASS.—Generally, the frame or main parts of a thing unfinished and unornamented, such as a building, when the work of the mason, bricklayer, and carpenter is completed, but before the joiner, the plasterer, and other artisans who fit it for use have begun their operations.

CARCASS-FLOORING.—The frame of timbers which supports the floor-boards above and the ceiling below.

CARCASS-ROOFING.—The frame of timber work which spans the building, and carries the slate boarding and other covering.

CARPENTER'S RULE.—A folding rule of boxwood; in England generally 2 feet, and in Scotland 3 feet in length.

CARPENTER'S SQUARE. See SQUARE.

CARPENTRY.—The art of cutting, joining, and framing together the timbers essential to the stability of a structure. See p. 120.

CARPENTRY AND JOINERY.—Distinction between, p. 120.

CARRIAGE OF A STAIR.—The timber frame which supports the steps of a wooden stair. See p. 196.

CARTOUCHE.—1. A roll or scroll.—2. A tablet formed like a sheet of paper, with the edges rolled up, either to receive an inscription or for ornament.—3. A kind of blocks or modillions used in the cornices of apartments.

CARYATIDES.—Figures of women in long robes, after the Asiatic manner, used in the place of columns as supports for an entablature.

Caryatid.

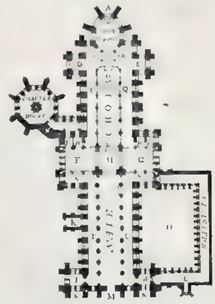
CASE-BAGS.—The joists framed between a pair of girders in naked flooring.

CASED SASH-FRAMES.—Sash-frames hung in cases with ropes and pulleys, so as to slide freely up and down.

CASEMENT.—1. A compartment between the mullions of a window, but more generally a glazed sash or frame hinged to open like a door.—2. A hollow moulding equal to one-sixth or one-fourth of a circle.

CASTING, WARPING, OR BUCKLING.—The bending of the surfaces of a piece of timber from their original state, caused either by the weight of the material or by unequal temperature, unequal moisture, or the want of uniformity of texture.

CATHEDRAL.—The see or seat of a bishop; the principal church in a diocese, so called from possessing the episcopal chair, called *cathedra*.



Plan of Wells Cathedral.

A, Apse or apsis. B, Altar, altar-platform, and altar-steps. D E, Eastern or lesser transept. F G, Western or greater transept. H, Central tower. I J, Western towers. K, North porch. L, Library or registry. M, Principal or western doorway. N N, Western side doors. O, Cloister-yard or garth. P Q, North and south aisles of choir. R S, East and west aisles of transept. T U, North and south aisles of nave. R R, Chapels. V, Rood-screen or organ-loft. W, Altar of Lady Chapel.

Many of the terms used to designate the different parts of a cathedral are illustrated and explained by the annexed woodcut and its references.

CATHERINE WHEEL.—In Gothic architecture, a large circular window, or circular compartment in the upper portion of a window, filled with radiating divisions or with a rosette.

CATHETUS.—A perpendicular line supposed to pass through the middle of a cylindrical body; the axis of a cylinder; the centre of the Ionic volute.

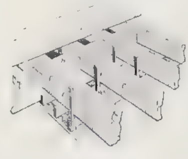
CAVETTO.—A hollow member or round concave moulding containing the quadrant of a circle, and used as an ornament in cornices and between the tori of the base of the Ionic, Corinthian, and other orders.

CAULKING.—The mode of fixing the tie-beams of a roof, or the binding and bridging joists of a floor, on the wall-plates; notching. Called also *cocking* (which see).

CEDAR WOOD.—Properties and uses of, p. 119.

CEILING.—The plaster or other covering which forms the roof of a room.

CEILING-JOISTS.—Joists to which the ceiling of a room is attached. They may be nailed to the under side of the binding-joists, or worked into



their sides, or suspended from the upper joists by straps. In the figure, *a* is the flooring; *b*, the girder; *c c*, the bridging-joists; *d d*, the ceiling-joists; and *e e*, the straps.

CEILING-JOISTS.—Rules for determining the strength of, p. 155.

CENTRE OR CENTERING.—The mould or timber frame on which any arched or vaulted work is constructed.

CENTRE-BIT.—A tool for boring large circular holes. See BIT.

CENTRES.—Tredgold's theory of the pressure of the arch stones on the, p. 172.

CENTRES.—Smeaton's observations on his design for the centre of Coldstream Bridge, p. 173.

CENTRES illustrated and described —

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Centre for an arch of small span, .	LVII.	1 4	173
Centre with intermediate supports,	LVII.	5, 6	173
Centre with radiating struts, . .	LVII.	7	173
Centre of a bridge over the river Don, 75 feet span, . . .	LVII.	8	173
Centre of Gloucester Overbridge, .	LVIII	1	173
Centre of Dean Bridge, Edinburgh,	LVIII.	2	174
Centre of Cartland Craigs Bridge,	LVIII.	3	174
Centre of Ballochmyle Viaduct, .	L.	6-10	174
Centre of railway viaduct over the Union Canal, near Falkirk, .	LV.	7	174
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Centre of viaduct over the Lugar Water, ...	LVI.	3, 4	175
Centre of Waterloo Bridge, London,	LIX.	1	175
Centre of bridge over the Seine at Neuilly, ...	LIX.	2	175
Centre designed by Mr. White, .	LIX.	3	175

CENTRES, mode of supporting, adopted at the Bridge of Nemours, p. 175.

CENTRES, mode of striking, adopted at Chester Bridge, p. 175.

CENTRES, mode of striking, adopted at Gloucester Bridge, p. 176.

CHAIN MOULDING.—An ornament of the Norman period sculptured in imitation of a chain.

Chain moulding.

CHAIN-TIMBERS.—Bond timbers of a larger size than usual, introduced to tie and strengthen a wall. The timbers are usually of the dimensions of a brick.

CHAIR-RAIL.—A plate of timber attached to a wall to prevent injury to the plaster from the backs of chairs.

CHAMFER.—To cut in a slope.

CHAMP.—A flat surface.

CHANCEL.—That part of the choir of a church between the altar or communion table and the balustrade or railing that incloses it, or that part where the altar is placed, formerly inclosed with lattices or cross bars, as now with rails. See CHOIR, as to the arbitrary use of the two words.

CHANTLATE.—A piece of wood fastened near the end of a rafter, and projecting beyond the wall, to support two or three rows of slates or tiles, so placed as to prevent the rain-water trickling down the wall.

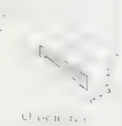
CHAPITER.—The upper part of the capital of a column or pillar.

CHAPLET.—A small cylindrical moulding carved into beads and the like.

CHAPS in trees, p. 97.

CHAPTREL.—The capital of a column supporting an arch; an impost.

CHASE-MORTISE OR PULLEY-MORTISE.—A manner of mortising transverse pieces into parallel timbers already fixed. One end of the transverse piece is mortised into one of the parallel pieces, and a long mortise being cut in the other parallel piece, the other end of the transverse piece is let into it, by making it radiate on its already mortised end. In this way, ceiling-joists are fixed to the bridging-joists.



CHEEKS OF A MORTISE, p. 147.

CHESTNUT WOOD.—Properties and uses of, p. 113.

CHEVAL-DE-FRISE.—A piece of timber pointed with iron and traversed with wooden spikes. Used in military operations.

CHEVRON.—A carved decoration, consisting of mouldings ranging in zigzag lines, peculiar to the Norman style of architecture. It is called also *zig-zag* and *dancette*.

Chevron Moulding

CHIMNEY.—A body of brick or stone, erected in a building, containing a funnel or funnels, to convey smoke and other volatile matter through the roof, from the hearth or fire place, where fuel is burned. The lower part of the chimney in the room or apartment is called the *fire-place;* the bottom or floor of the fire-place is called the *hearth,* sometimes the *inner hearth;* the stone or marble in front of the hearth is called the *slab* or *outer hearth.* The vertical sides of the fire-place opening are termed the *jambs,* and the lintel which lies on them is called the *mantle.* The inner wall of the fire-place is called the *breast,* and the other two sides are termed the *covings.* The cylindrical or parallelogramical tube which conveys the smoke from the fire-place to the top of the chimney is called the *flue.* The fire-place cavity being much wider than the flue, they are joined by a tapering part, which is termed the *funnel;* the lower part of the funnel is termed the *gathering,* or *gathering of the wings;* and the junction of the funnel and flue is called the *throat.* When several chimneys are carried up together, the mass is called a *stack* of chimneys. The part of the chimney carried above the roof, for discharging the smoke, is the *chimney-shaft,* and the upper part of the shaft is the *chimney-top* or *head.*

CHISEL.—A cutting tool, of which there are many different sorts, used by carpenters, joiners, bricklayers, masons, and smiths. — *Carpenters' chisels* are: 1. The socket or heading chisel, employed in cutting mortises. Its blade is from $1\frac{1}{4}$ inch to $1\frac{1}{2}$ inch wide, and it gets its name from the top of its stem being formed into a socket to receive a wooden handle. 2. The mortise-chisel, which has a button on the top of its stem, with a tang for insertion into a wooden handle. 3. The ripping chisel, which is generally an old socket-chisel. — *Joiners' chisels.* 1. The mortise chisel, the same as that of the carpenter's, and of various sizes. 2. The firmer. 3. The paring-chisel. 4. The drawing knife, which is an oblique-ended chisel.—*Masons' chisels,* called by them *tools.* These are from 6 to 8 inches long, and have a button formed on the head of the stem, to receive the blows of the mallet or hammer. 1. The broad boaster or batt, which is from 3 to $4\frac{1}{2}$ inches wide on the cutting edge. 2. The boaster, which is from 2 to 3 inches wide. 3. Tools of the same kind, called from their width the $1\frac{1}{2}$-inch tool, the 1-inch tool, &c. 4. The point, which is from $\frac{1}{16}$ to $\frac{3}{8}$ inch wide. There are, besides these, a great variety of chisels or tools used for various kinds of stone; as pitching tools, for squaring flags, granite tools, &c.—*Bricklayers' chisels.* These are of the same nature as the chisels of the masons, and, in addition, the bricklayers use the ripping chisel and the iron chisel, which is a small crowbar.—*Smiths' chisels* are similar to those of the masons, but shorter.

CHOIR.—The part of a church where the services are chanted or recited, but the application of the term is generally restricted to the inner or eastern part of a cathedral, where service, more especially the musical part of it, is performed. It is separated by the transept from the nave or outer part. See woodcut, CATHEDRAL.—In churches the same part is called the *chancel.*

CHORD, The, and versed sine of the arc of a circle being given, to find the curve without having recourse to the centre. Prob. LXXXIV. p. 22.

CHORDS OF A TIMBER BRIDGE.—The horizontal longitudinal main timbers of the framing, p. 159.—To find the strains on, p. 160.

CHORDS, Line of, on the Sector,—Construction and use of, p. 37.

CHRISTIANIA TIMBER. See PINUS SYLVESTRIS, p. 116, 117.

CILERY.—Drapery or foliage carved on the heads of columns.

CINCTURE.—A ring or list at the top and bottom of a column, separating the shaft at the one end from the base, and at the other from the capital.

CINQUE-CENTO.—Literally 500, but used as a contraction for 1500, the century in which the revival of the architecture of Vitruvius took place in Italy, and applied to distinguish the architecture of the Italo-Vitruvian school generally—a school marked by the formation of the five orders, by the use of attached columns, unequal intercolumniations, broken entablatures, and the collocation of arches with columnar ordinances.—In decorative art, a term applied to that attempt at purification of style and reverting to classical forms introduced towards the middle of the 16th century, and practised by Agostino Busti and others, more particularly in the north of Italy. This style aimed at a revival of the gorgeous decorations of Rome, throwing out all those arbitrary forms which are never found in ancient examples, as the scrolled shield and tracery; and elaborating to the utmost the most conspicuous characteristics of Greek and Roman art, especially the acanthus scroll and the grotesque arabesques, abounding with monstrous combinations of human, animal, and vegetable forms in the same figure or scroll-work, but always characterized by extreme beauty of line. The term is often loosely applied to ornament of the 16th century in general, properly included in the term *Renaissance.*

CINQUE-FOIL.—An ornament in Gothic architecture, consisting of five cuspidated divisions. See FOLIATIONS.

CIRCLE AND CIRCULAR FIGURES.—Construction of, p. 18-22.

CIRCLE.—The circle contains a greater area than any other plane figure bounded by the same perimeter. The areas of circles are to each other as the squares of their diameters.—The chord and versed sine of a circle being given, to find its diameter. Rule: Divide the sum of the squares of the chord and versed sine by the versed sine: the quotient is the diameter.—To find the length of any given arc of a circle from its chord and the chord of half the arc. From eight times the chord of half the arc subtract the chord of the whole arc, and one-third of the remainder is equal to the length of the arc.—To find the area of a circle. Multiply the square of the diameter by ·7854.—To find the area of a sector of a circle. Multiply the length of the arc by its radius, and half the product is the area.—To find the area of the annular space between two concentric circles. Multiply the sum of the larger and smaller diameters by their difference and by ·7854.—Approximate rules for practical calculations:—

The diameter multiplied by 3·1416 is equal to circumference

The circumference multiplied by ·31831 is equal to the diameter

The square of diameter multiplied by ·7854 is equal to the area

The square root of area multiplied by 1·12837 is equal to diameter

The side of a square multiplied by 1·128 is equal to the diameter of a circle of equal area

The diameter multiplied by ·8862 is equal to the side of a square of equal area.

CIRCLE.—To inscribe a circle in a given triangle, p. 9.

CIRCLE.—To inscribe a circle within three given oblique lines, p. 9.

CIRCLE.—To cut off a segment from a circle that shall contain an angle equal to a given angle, p. 18.

CIRCLE.—To divide a circle into any number of equal or proportional parts by concentric divisions, p. 18.

CIRCLE.—To divide a given circle into three concentric parts, bearing the proportion to each other of 1, 2, 3, from the centre, p. 18.

CIRCLE.—To divide a circle into any number of parts equal to each other in area and perimeter, p. 19.

CIRCLE.—To raise perpendiculars to any point of an arc of a circle without finding the centre, p. 19.

CIRCLE.—To find the centre of a given circle, p. 16.

CIRCLE.—To draw a tangent to a circle passing through a given point in its circumference, p. 16.

CIRCLE.—To draw a tangent to a circle from a given point without the circumference, p. 16.

CIRCLE.—To find the point of contact between a given tangent and circle, p. 16.

CIRCLE.—Through three given points to describe the circumference of a circle, p. 17.

CIRCLE.—To describe a circle that shall touch two straight lines given in position and one of them at a given point, p. 17.

CIRCLE.—To draw a straight line equal to the circumference of a circle, p. 19.

CIRCLE.—To draw a straight line equal to any given arc of a circle, p. 19.

CIRCLE.—To construct a triangle equal to a given circle, p. 20.

CIRCLE.—To describe a rectangle equal to a given circle, p. 20.

CIRCLE.—Through three given points to describe an arc of a circle without finding the centre, p. 20.

CIRCLE.—Three points, neither equidistant nor in the same straight line being given, through which the arc of a circle is to be described, to find the altitude of the proposed arc, p. 21.

CIRCLE.—A segment of a circle being given, to complete the circle without finding the centre, p. 21.

CIRCLE.—To describe a circle by means of a carpenter's square or right angle, p. 21.

CIRCLE.—To describe the arc of a circle by two straight rods, the chord and versed sine being given, p. 21.

CIRCLE.—To describe the segment of a circle at twice by a triangular mould, the chord and versed sine being given, p. 21.

CIRCLE.—To find points in the curve of a segment of a circle by intersecting lines, p. 21, 22.

CIRCLE.—The chord and versed sine of an arc of a circle being given, to find the curve without having recourse to the centre, p. 22.

CIRCLE. — To describe a square equal to a given circle, p. 20.

CIRCLE.—The shadow thrown by a circle on the horizontal plane, p. 214.

CIRCLE.—The shadow of a circle on the vertical plane, p. 215.

CIRCLE.—To find the shadow of a circle on two planes, p. 215.

CIRCLE.—The shadow of a circle on a curved surface, p 215.

CIRCLE. — To find the shadow of a circle situated in the plane of the luminous rays, p. 215.

CIRCLE. — To find the shadow of a circle whose horizontal projection is perpendicular to a trace of a plane passing through the luminous ray, p. 216.

CIRCLES.—To find the point of contact of two touching circles, p. 18.

CIRCLES, contiguous, to describe,which shall also touch a given line, p. 18.

CIRCULAR CHAPS in trees. p. 97.

CIRCULAR SAW.—A saw with circular blade mounted on a spindle like a wheel, with teeth on its periphery. The teeth of circular saws are generally wider apart, more inclined, and wider set than the teeth of rectilinear saws.

CIRCULAR WINDOW. — To find the curvature of the sash-bar of a circular window, p. 189.

CIRCULAR WINDOW or Chord Bar.—To find the veneer for the cot-bar, p. 189. To find the mould for the radial bar, p. 189. To find the face-mould for the circular outside lining, p. 189. To obtain the moulds for the head of the sash-frame, p. 189. To obtain the mould for the under side of the sash, p. 189.

CLAMP.—1. An instrument made of wood or metal, with a screw at one end, used to hold pieces of timber together until the glue hardens; also, a piece of wood fixed to another in such a manner that the fibres cross, and thus prevent casting or warping.—2. Something that fastens or binds.—3. A piece of timber or iron used to fasten work together.

CLAMPING. — Fastening or binding by a clamp.

CLASP NAILS.—Nails with heads flattened, so as to clasp the wood.

CLASSIC ORDERS.—The Grecian Doric, Ionic, and Corinthian, and the Roman, Tuscan, Doric, Ionic, Corinthian, and Composite orders are generally thus distinguished.

CLEAR.—Free from interruption.—*In the clear*, the nett distance between any two bodies, without anything intervening.

CLEARCOLE, or Claircol.—A composition of size and white lead.

CLERE-STORY, Clair-Story.—The upper tier of lights of the nave, choir, and transepts of a church. The name is by some derived from the *clair* or light admitted through its windows—by others from the windows being clear of the roof of the aisle—and by others from that story being clear of rafters, joists, or any obstruction.

CLINKER.—A brick more thoroughly burned than the others, by being nearer to the fire.

CLOISTER. – Literally, a close or inclosed place. An edifice is said to be in form of a cloister when there are buildings on each side of a court.

CLOSE-STRING.—In dog-legged stair-cases, when the steps are housed into the strings. See p. 196.

CLOSER.—The stone or brick laid to close the defined length of any course.

CLOUT-NAIL. — A flat-headed nail with which iron-work is usually fastened to wood.

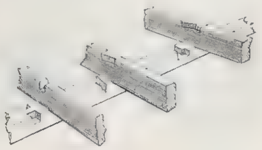
CLOWRING, Clouring.—In stone-cutting, the same as *wasting* (which see).

CLUSTERED COLUMN.—A pier which is formed of a congeries of columns clustered together, either attached or detached.

COB-WALL.—A wall formed of unburned clay, mixed with chopped straw and occasionally with layers of long straw, to act as a bond.

COCK-BEAD.—A bead which projects from the surface of the timber on both sides.

COCKING, Cogging.—A mode of notching timber; called also *caulking*. A variety of notch-



ing, which will be understood by inspection of the figure.

CODDINGS.—A term used in Scotland to denote the base or footings on which chimney-jambs are set in the ground-floor of a building.

COFFER.—A panel deeply recessed in any soffit or ceiling.

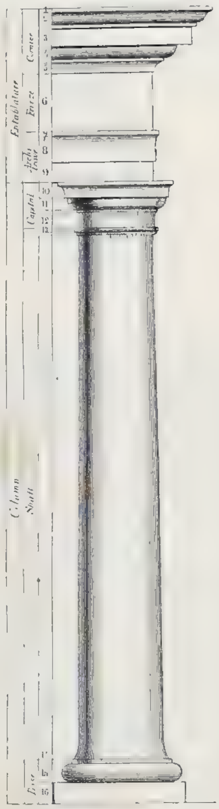
COIN, Coigne —The corner of a building. —*Coin-stones*, corner-stones. - See Quoin.

COLLAR of a Shaft.—The annulet.

COLLAR-BEAM.—A beam extending between the two opposite rafters of a framed principal above the tie-beam, or between two common rafters.

COLONNADE.—A range of columns.

COLUMN.—A long solid body called a shaft, set vertically on a congeries of mouldings, which forms its base, and surmounted by a spreading mass, which forms its capital. In strictness, the



Tuscan Column.

1. Fillet. 2. Cyma Recta. 3. Corona. 4. Ovolo. 5. Cavetto. 6. Frieze. 7. Fillet. 8. Upper Fascia. 9. Lower Fascia. 10. Abacus. 11. Ovolo. 12. Colarino or Neck. 13. Astragal. 14. Apophyges. 15. Torus. 16. Plinth.

term column should be applied only when the shaft is in one piece. When it is built up of several pieces it is a pillar or pile. Columns are distinguished by the styles of architecture to which they belong; thus, there are Hindoo, Egyptian, Grecian, Roman, and Gothic columns. In classic architecture they are further distinguished by the name of the order to which they belong—as Doric, Ionic, and Corinthian columns; and again by some peculiarity of position, of construction, of form, or of ornament—as attached, twisted, cabled, indented, rusticated columns. Columns, although chiefly used in the construction or adornment of buildings, are also used singly for various purposes. Thus, there are the *astronomical* column, whose use is sufficiently indicated by its name; the *gnomonic* column, used to support a dial; the *chronological* column, inscribed with a record of historical events; the *crucifcral* or cross-bearing column; the *funereal* column, used to sustain an urn; the *miliary* column, set up as a centre from which to measure distances; the *itinerary* column, pointing out the direction of diverging roads; the *rostral* column, adorned with the prows (*rostra*) of ships, to commemorate a naval victory; the *sepulchral* column, erected over a tomb; the *triumphal* column, dedicated to the hero of a victory; the *manubial* column, adorned with trophies, spoils, &c., and many others.

COLUMNS.—Diminution of, p. 184.

COLUMNS.—Gluing up, p. 184.

COMMON JOISTS.—Those in naked flooring to which the boards are attached, called also *bridging-joists*. See Floors, p. 150.

COMMON RAFTERS.—Those to which the slate-boarding or lathing is attached.

COMMON ROOFING.—Roofing consisting of common rafters only, without principals.

COMMON PITCH.—A term applied when the length of the rafters is equal to about three-fourths of the span within the walls. In this case the angle formed at the ridge by the rafters is 83° 37′, and the perpendicular height of the gable is 5·9ths of the width of the building in the inside.

COMPASS-HEADED ARCH.—A semicircular arch.

COMPASS-PLANE.—A plane with a round sole.

COMPASS-ROOF.—One in which the tie from the foot of one rafter is attached to the opposite rafter at a considerable height above its foot.

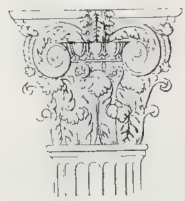
COMPASS-SAW.—The same as *bow-saw*.

COMPASS-WINDOW.—A bay-window on a circular plan.

COMPASSES with moveable legs, how to use, p. 32.

COMPOSITE ARCH.—A lancet or pointed arch.

COMPOSITE ORDER.—The last of the five Roman orders, and so called because composed out of parts from the other orders. Its capital has a vase like the Corinthian, surrounded by two rows of acanthus leaves; the top of its vase is surmounted by a fillet, an astragal is placed over that, and on the astragal an ovolo; over this the volutes



Composite Capital.

roll angularly, till they meet the tops of the upper row of leaves, on which they seem to rest. On the top of each volute is an acanthus leaf, curling upwards so as to sustain the horn of the abacus. The abacus is like that of the Corinthian capital. The height of the column is 10 diameters, its capital occupies $1\frac{1}{4}$ diameter, and its base nearly $\frac{1}{2}$ diameter. The entablature is $2\frac{1}{2}$ diameters and $2\frac{1}{2}$ minutes in height; of this, 46 minutes are given to the architrave, $44\frac{1}{2}$ to the frieze, and 62 minutes to the cornice. Its architrave has only two fascias, and its cornice sometimes varies from the Corinthian in having, instead of the modillion and dentil, a species of double modillion plain on the surface. The examples at Rome are in the arch of Septimus Severus, the arch of the Goldsmiths, the arch of Titus, the temple of Bacchus, and the Baths of Dioclesian.

COMPOSITION OF FORCES. p. 124.

COMPOUND PIER.—A clustered column is sometimes so called.

CONCAMERATE.—To arch over; to vault.

CONCAVE SURFACE OF REVOLUTION.—To find the shadow of a, p. 223.

CONCAVE CYLINDRICAL SURFACE.—To find the shadow of a, p. 218.

CONCAVE INTERIOR SURFACE OF A CONE.—To find the shadow on the, p. 219.

CONCAVE INTERIOR SURFACE OF A HEMISPHERE.—To find the shadow on the, p. 220.

CONCENTRIC.—Having a common centre, as concentric circles, ellipses, spheres.

CONE. -To find the surface of a cone. Multiply half the circumference of the base by sum of the slant side and the radius of the base; the product will be the whole surface.—To find the solidity of a cone. Multiply the area of the base by the perpendicular height, and one-third of the product will be the solid content.—To find the surface of the frustum of a cone. Add the circumferences of the two bases together, and multiply half the sum by the slant height for the upright or curved surface, to which add the areas of the two bases for the whole surface.—To find the solid content of the frustum of a cone. Find the areas of the two ends, multiply them together, and take the square root of their product; this, added to the two areas and the sum multiplied by a third of the perpendicular height, will give the solidity.

CONE.—To draw the sections of a cone made by a line parallel to one of its sides, p. 68, Plate I. Figs. 2 and 3.—To draw the sections of a cone made by a line cutting both its sides, p. 68, Plate I. Fig. 1.

CONE.—To construct the projections of a cone intersected by a plane, p. 59.

CONE.—To find the shadow of a cone thrown on a sphere, p. 222.

CONE.—To construct the projection of a cone, p. 85.

CONE.—Tangent plane to a cone. p. 61.

CONES.—To find the limits of shade on, and the shadow of cones, under various conditions, p. 222.

CONES.—To find the covering of frustum of cones made by various sections, p. 74, Plates II. and III.

CONES.—To find the projections of intersecting cones, p. 64–66.

CONES, right and oblique development of, p. 71, 72.

CONGÉ.—The cavetto which unites the base and capital of a column to its shaft.

CONIC GROINS. -Groins produced by the intersection of equal conical vaults, p. 76.

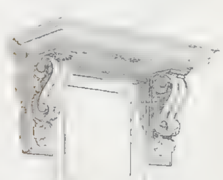
CONIC SECTIONS.—The ellipse, the parabola, and the hyperbola methods of drawing those figures, and approximations to those figures, p. 22.

CONICAL ROOF.—Construction of, Plate XXXIII. p. 145.

CONIFERÆ, or resin-producing trees, p. 115. Their various products, p. 115. Where obtained from, p. 115, 116. Mode of transporting them from the Alpine forests; inclined plane of Alpnach, p. 116. Summary of the purposes for which the various European kinds are best adapted, p. 116.

CONO-CYLINDRIC GROINS.—To find the angle ribs of, p. 79.

CONSOLE.—A projecting ornament used as



Cornice supported by Consoles.

a bracket. It has for its outline generally a curve of contrary flexure.

CONTINUOUS IMPOST.—In Gothic architecture, the mouldings of an arch when carried down to the ground without interruption, or anything to mark the impost joint.

CORBEL.—1. A structure of stone, brick, wood, or iron, incorporated with a wall, and projecting from its vertical face, to support some superincumbent member, and dilating from its lowest point upwards. Corbels are of a great variety of forms, and are ornamented in many ways. They are of frequent occurrence in Pointed architecture, forming the supports of the beams of floors and of roofs, the machicolations of fortresses, the labels of doors and windows, &c.—2. The vase or tambour of the Corinthian column; so called from its resemblance to a basket.

Fig. 1 Fig. 2

Corbels.

Fig. 1. From [illegible] Church, Northamptonshire. Fig. 2. From Stone Church, Kent.

CORBEL, *v.*—To dilate by expanding every member of a series beyond the one under it.

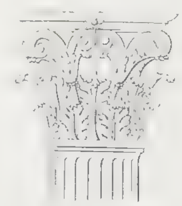
CORBEL-STEPS.—Steps into which the sides of gables from the eaves to the apex are broken; sometimes called *corbie-steps.*

CORBEL-TABLE.—A term in mediæval

Corbel-table.

architecture, applied to a projecting course and the row of corbels which support it.

CORINTHIAN ORDER.—The only Grecian example of this order remaining, is in the choragic monument of Lysicrates, vulgarly called the Lanthorn of Demosthenes, at Athens. It is an elegant structure, consisting of a rusticated quadrangular basement, surmounted by a cyclostyle of six Corin-



Corinthian Capital [illegible]

thian columns attached to a wall, which rises as high as the top of their shafts. The order here, although elevated on a podium, has yet the graduated stylobate that seems to be an essential feature in Greek architecture. The stylobate is rather more than a diameter in height, and is divided into three steps, the two lowest of which are equal and have vertical faces, and the third is of less height and moulded on the edges with exquisite taste, preparing the eye for the ornate order above it. The column is ten diameters in height, of which the base occupies rather more than a third of a diameter, and the capital a diameter and rather less than a third. The shaft diminishes with entasis to five-sixths of its lower diameter, and has twenty-four flutes, with fillets between. The flutes are semi-ellipses, and finish at the top in leaves, to which the fillets serve as stalks. The hypotrachelium is a groove under the capital. The core of the capital is a perfect cylinder, rather less than the upper diameter of the shaft. This is surrounded at the bottom by a row of water leaves, about a sixth of the height of the capital, and bending outwards; above this is another row of acanthus leaves, with rosettes attaching them to the cylinder. This row is in height equal to a third of the height of the capital. The remaining height is occupied by helices and tendrils and the abacus. The entablature is $2\frac{1}{12}$ diameters in height, and if this is divided into minutes, or 60th parts of the lower diameter, the architrave occupies about 53 of these, the frieze 41, and the cornice 51. The architrave is divided into three fascias; the faces of these incline inwards, so that their lower angles are in the same plane. The frieze is enriched with sculptures. The cornice consists of a bed-moulding, a broad dentilled member supporting a cyma-recta, with fillets serving as the bed-moulding of the corona; the coron is crowned by a simple ovolo and fillet.

ROMAN-CORINTHIAN.—The Corinthian order in the hands of the Romans, unlike the Doric and Ionic, did not suffer deterioration, but on the contrary acquired fulness, strength, and richness, which rendered it one of the most beautiful and appropriate architectural ornaments. Of no other order are the existing examples so numerous or so varied in proportion or ornamentation. Among these, the order of the temple of Jupiter Stator, of Antoninus and Faustina, of the Pantheon, and of the Maison Quarrée at Nismes, may be enumerated. Taking the first of these as a guide, the following are the proportions of this order. The column is 10 diameters high, the base occupying of this $\frac{1}{2}$ diameter, and the capital $1\frac{1}{3}$ diameter. The Attic base is oftenest used. The capital is composed of two rows of acanthus leaves, six in each row, placed upright, side by side, but not in contact. From these spring helices and tendrils, trussed with foliage, and above all is the abacus, with moulded and enriched faces. The lower row of leaves is two-sevenths of the height of the capital, the upper two-thirds of its height, and the abacus is one-seventh of the height. The entablature of the temple of Jupiter Stator is more than $2\frac{1}{2}$ diameters in height. The architrave and frieze have about $1\frac{1}{3}$ diameter between them, and the cornice is therefore more than 1 diameter high. In the order of the Pantheon, the architrave and frieze are about the same height as above, and the difference is in the cornice alone; it has therefore been proposed to make the whole height of the entablature $2\frac{1}{4}$ diameters, and to divide three-fifths of this between the architrave and frieze. The architrave is divided into three unequal fascias; the middle fascia is richly ornamented; the heads which separate the fascias are carved, and the architrave moulding is enriched. The frieze is in some cases quite plain, in others it is sculptured or enriched with foliage. The cornice consists of a deep bed-mould, composed of a bead, an ovolo, and fillet, a plain vertical member sometimes cut into dentils, another bead, a cyma-reversa or ovolo, and fillet. When modillions are used, this is surmounted by a plain member, with a cyma-reversa above it, on which the modillions are placed, and the cyma breaks round them. The modillions are horizontal trusses or consoles, finishing at the inner end in a large and at the outer end in a small volute, and having under them generally an acanthus or other leaf. Above the modillions is the corona, sometimes enriched with vertical flutes, and its crowning mouldings, which are a narrow fillet, an ovolo, a wider fillet, and then a cyma-recta. The soffit of the cornice is generally coffered between the modillions, and in every coffer there is a flower. The height of the pedestal is 3 diameters.

CORNICE.—1. The highest part of an entablature resting on the frieze. See woodcut, COLUMN.—2. Any congeries of mouldings which crowns or finishes a composition externally or internally.

CORONA.—A member of a cornice situated between the bed-moulding and the cymatium. It consists of a broad vertical face, usually of considerable projection. Its soffit is generally recessed upwards, to facilitate the fall of rain from its face, and thus to shelter the wall below. This among workmen is called the *drip,* and by the French *larmier,* and this last term is often used by English writers. See woodcut, CYMA-RECTA.

CORPSE-GATE. See LICH-GATE.

CORPSING.—A shallow mortise sunk in the face of a piece of stuff. See p. 200.

COULISSE.—1. A piece of timber with a channel or groove in it, such as that in which the side scenes of a theatre move.—2. The upright grooved posts of a floodgate or sluice.

COUNTER-LATH. -A lath, in tiling, placed between every two gauged ones so as to make equal spaces.

COUNTERBRACE. Fig. 474, p. 159.

COUNTERBRACES, Strains on.—How to determine, p. 161.

COUNTERSINK, *v.*—To form a cavity in timber or other material for the reception of something, such as the head of a bolt.

COUNTESSES, IN SLATING.—Slates whose dimensions are 1 ft. 8 in. long and 10 inches wide.

COUPLED COLUMNS.—Columns disposed in pairs. The two columns of a pair are half a diameter apart.

COUPLES, COUPLE CLOSE.—A pair of opposite rafters in a roof nailed together at the top, where they meet, and connected by a tie at the bottom, or by a collar-beam higher up.

COURSE.—A continuous range or stratum of material of the same height throughout its extent. See RANDOM COURSE.

COUSSINET.—The crowning-stone of a pier, lying immediately under the arch.—The ornament in an Ionic capital between the abacus and the echinus.

COVE.—Any kind of concave moulding. The

concavity of a vault; commonly applied to the curve which is sometimes used to connect the ceiling with the walls of a room.

COVE BRACKETTING.—The wooden skeleton mould or framing of a cove. Applied chiefly to the bracketting for the cove of a ceiling.

COVED CEILING.—A ceiling springing from the walls with a curve.

COVERINGS OF SOLIDS, p. 69.

COVING. Same as *Cove.*

COVING OF A FIRE-PLACE.—The vertical sides which connect the jambs with the breast.

CRADLE.—A name given to a centering of ribs latticed with spars, used in building culverts.

CRADLE-VAULT.—An improper term for a cylindrical vault.

CRADLING.—Timber framing for sustaining the lath and plastering of a vaulted ceiling. Also, the framework to which the wooden entablature of a shop front is attached.

CRAMP.—A piece of iron bent at the ends, serving to hold together pieces of timber, stone, &c.

CRAMPOONS.—An apparatus used in the raising of timber or stones, consisting of two hooked pieces of iron hinged together, somewhat like double calipers.

CRAPAUDINE DOORS.—Those which turn on pivots at top and bottom. Doors hung with centre-pin hinges.

CREASING.—A projecting row of plain tiles placed under the brick on edge coping of a wall.—*Double-creasing* consists of two rows of tiles used for the same purpose and breaking joint.

CRENELLATED MOULDINGS.—Mould-

Crenellated or Embattled Moulding

ings embattled, notched, or indented, used in the Norman style.

CRENELLATION.—The making of crenelles.

CRENELLES.—1. The openings in an embattled parapet.—2. The loopholes and other openings in the walls of a fortress, through which arrows or other missiles might be discharged.

CRESTS.—Carved work on the top of a building. The ridges of roofs, the copes of battlements, and the tops of gables were also called *crests.*

CRIPLINGS.—Spars set up as shores against the sides of buildings.

CROCKET.—In Gothic architecture, an ornament placed at the angles of pinnacles, gables, canopies, and other members. In its usual form the

Crockets

crocket is a foliated band, covering the angle of the member to which it is applied, swelling out at regular intervals into knobs with considerable projection. These knobs assume generally the form of tufts of leaves, but often also the figures of animals.

CROSETTES.—1. The returns on the corners of architraves of doors, &c., called also *ears, elbows, ancones.*—2. The small projecting pieces in arch stones which hang upon the adjacent stones.

CROSS-GARNETS. — Hinges having a long strap fixed to the door or closure, and a shorter right-angled strap fixed to the frame. Termed in Scotland *cross-tailed hinges.*

CROSS-GRAINED STUFF.—Timber having the grain or fibre not corresponding to the direction of its length, but crossing it, or irregular. Where a branch has shot from the trunk of a tree, the timber of the latter is curled in the grain.

CROSS-SPRINGER.—In vaulting, is the diagonal rib of a groin.

CROSS-VAULTING.—That which is formed by the intersection of two or more simple vaults. When the vaults spring at the same level, and rise to the same height, the cross-vault is termed a *groin.* When one of the vaults is larger in span and greater in height than the other, a compound word is used to denote the combination. Thus, when both vaults are cylindrical, the groin is termed *cylindro-cylindric,* the qualifying prefix ending in *o* denoting always the body range or greater vault, and the terminal word denoting the smaller vault which intersects. See GROINS, p. 76.

CROWDE OR CROUD.—The crypt of a church.

CROWN OF AN ARCH.—Its vertex or highest point.

CROWN MEMEL TIMBER. See PINUS SYLVESTRIS, p. 116, 117.

CROWN-POST.—The same as *king-post.*

CUBE.—A rectangular prism, with all its six sides equal.—To find the solid contents of a cube. Find the area of one of its sides, and multiply it by the height. To find the surface of a cube. Find the area of one of its sides, and multiply it by 6.

CUBE.—To construct the projection of a cube, p. 53.

CULLIS. Same as *coulisse.*

CULTIVATION OF TREES, p. 96.

CULVERT.—A passage under a road or canal, covered with a bridge; an arched drain for the passage of water.

CUNEOID.—To find the envelope for the frustum of a cuneoid, p. 74, Plate III. Fig. 3.

CUNEOID, to draw the section of a cuneoid, made by a line cutting both its sides, p. 68, Plate I. Fig. 4, Nos. 1–4.

CUPOLA.—A spherical vault at the top of an

Cupola, Radcliffe Library, Oxford

edifice; a dome, or the round part of a dome. The Italian word signifies a hemispherical roof, covering a circular building like the Pantheon at Rome or the Round Temple at Tivoli.

CURB.—A frame round the mouth of an opening; a curb-plate (see next word).

CURB-PLATE.—1. The wall-plate of a circular or elliptical domical roof, or of a skylight.—2. The plate which receives the upper rafters of a curb or Mansard roof.—3. The circular frame of a well.

CURB-RAFTERS.—The upper rafters of the curb or Mansard roof.

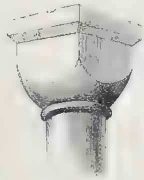
CURB-ROOF.—The same as a *Mansard roof.* See p. 140.

CURLING-STUFF.—Timbers in which the fibres wind or curl at places where boughs have shot out from the trunk of the tree.

CURTAIL-STEP.—The first step of a stair when its outer end is finished in the form of a scroll. See p. 196.

CURVED SURFACES, intersections of, projection, p. 63.

CUSHION-CAPITAL.—1. A capital having a resemblance to a cushion pressed by a weight.—



Norman Cushion-capital

2. The variety of capital most prevalent in the Norman style. It consists of a cube rounded off at its lower angles.

CUSPS.—The points or small projecting arcs terminating the internal curves of the trefoiled, cinquefoiled, &c., heads of windows and panels in

Cusps

1 Monument of Edward III., Westminster Abbey (brass). 2. Henry VII.'s Chapel. 3. Monument of Sir James Douglas, Douglas Church 4. Beauchamp Chapel, Warwick.

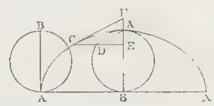
Gothic architecture. They are also called *featherings.*

CUT AND MITRED STRING, p. 196.

CUT-BRACKETS.—Those moulded on the edge.

CUT-ROOF.—A truncated roof.

CYCLOID.—One of the transcendental curves described by a point in the circumference of a circle, which rolls along an extended straight line



until it has completed a revolution. In the figure let the circle B C A make one revolution on the straight line A B A, then the curved line A C A A, traced out by a point in the circumference A, is a cycloid. The following are some of its properties:—The base A B A is equal to the circumference of the generating circle; and A B, the axis of the cycloid, is of course equal to its diameter. If the generating circle be placed in the centre of the cycloid, the diameter A B, coinciding with its axis, and from any point C in the curve there be drawn the tangent F C, the ordinate C D E, perpendicular to the axis and the chord of the circle A D; then C D is equal to the circular arc A D; the cycloidal arc A C is double the chord A D; the semicycloid A C A is double the diameter of the circle A B, and the tangent C F is parallel to the chord A D.

CYLINDER.—A round solid of uniform thickness, of which the bases are equal and parallel circles.—To find the surface of a cylinder. Rule: Multiply the circumference of the base by the height, and add the area of the two bases.—To find the solid content of a cylinder. Rule: Find the area of the base, and multiply it by the perpendicular height or length.

CYLINDER.—To construct the projections of a cylinder, p. 57, 58. The projections of a cylinder cut by a plane, p. 58. To find the projections of a cylinder intersecting a sphere, p. 64. To construct the projections of a cylinder penetrated by a scalene cone, p. 66.

CYLINDER, a, tangent planes to, p. 60, 61.

CYLINDERS.—Development of cylinders, p. 71. To find the projections of cylinders intersecting each other, p. 63. To find the coverings of right and oblique cylinders, and cylindric and semicylindric surfaces, p. 73, Plate II. To find the shadows of cylinders under various conditions, p. 222.

CYLINDRIC GROINS.—Those produced by the intersection of cylindric vaults of equal span and height. See p. 76.

CYLINDRIC SECTION, To describe a, through a line given in position, p. 68, Plate I. Fig. 5

CYLINDRIC SECTION made by a curved line cutting the cylinder, to describe, p. 68, Pl. I. Fig. 6.

CYLINDRICAL RING.—To find the section of a, p. 69, Plate I. Fig. 9.

CYLINDRICAL VAULT.—A vault in the form of a half-cylinder, without either groins or ribs. Its vertical section is a semicircle, or some lesser arc. It is called also *cradle-vault, waggon-vault,* and *barrel-vault.*

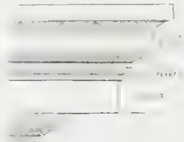
CYLINDRICAL VAULTS.—To determine the horizontal divisions of the radial panels of, p. 83.

CYLINDRO CYLINDRIC VAULT.—A vault generated by the intersection of one cylindrical vault with another of greater span and height. See CROSS VAULTING, and text, p. 76.

CYLINDRO SPHERIC GROIN.—One formed by the intersection of a sphere with a cylinder of greater span and height. See p. 76.

CYLINDROID.—A solid, which differs from a cylinder in having ellipses instead of circles for its ends or bases.

CYMA RECTA.—A moulding formed of a curve of contrary flexure, concave at the top and convex at the bottom. It takes its name from its contour resembling a wave — hollow above and swelling below



Cymatium, or Cyma Recta

CYMA RECTA, The.—To describe, p. 179.

CYMA REVERSA. A moulding formed of the above curve reversed. It is more commonly called an *ogee*. See MOULDINGS.

CYMA REVERSA, The.—To describe, p. 179.

CYMATIUM.—The *cyma recta*.

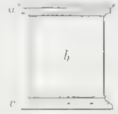
CYPRESS.—The common or evergreen cypress tree (*Cupressus sempervirens*), a native of the islands of the Archipelago, of Greece, Turkey, and Asia Minor, where it grows to a great size. It is abundant in Italy, and said to have been introduced into that country from Greece. In Britain it seldom attains a height exceeding 40 feet. It is remarkable for its upright habit of growth and uniformity of taper. It is cultivated as an ornamental tree, and used for the embellishment of tombs and cemeteries, as a symbol of man's last resting-place. The best specimen in Britain is at Stretton Rectory, Suffolk, measuring sixty-three feet high and two feet in diameter. The timber of this tree possesses all the qualities of durability ascribed to the cedar. There are many remarkable instances of its durability recorded. The doors of St. Peter's, at Rome, lasted from the time of Constantine to that of Eugene III. (1100 years), and were found perfectly sound when removed. The statue of Jupiter, in the Capitol (according to Pliny), had existed 600 years, and showed no symptom of decay. The cypress doors of the temple of Diana appeared quite new when 400 years old

It is not, however, of sufficient size or numbers to be generally known in this country; but it is in common use in Candia and Malta.

D.

DABBING, DAUBING, OR PICKING.—A method of working stones, in which the face of the stone is reduced to a uniform surface and brotched, and the beds and joints worked; it is then draughted as for nidging. The daubing is then performed with a pick-shaped tool, or with a faced hammer, like a nidging hammer, indented so as to form a series of points, and by the strokes of this the whole surface is covered with minute holes. Daubing has the appearance of strength and neatness, and is adapted for gateways, bridge work, and the basements of houses. When the stone is not hard in quality, this mode of dressing is open to the same objections as nidging.

DADO.—That part of a pedestal included between the base and the cornice; the die. —In apartments, the dado is that part of the finishing between the base and the surbase.



Dado.

[illegible]

DAIS.—1. A platform or raised floor at the upper end of an ancient dining-hall, where the high table stood.—2. A seat with a high wainscot back, and sometimes with a canopy, for those who sat at the high table.—3. The high table itself.

DANCE.—In a stair of mixed flyers and winders, the distribution of the inequality of width of the inner end of the latter among them, and a number of the flyers, is called *making the steps dance*. See p. 198.

DANCETTE.—The chevron or zigzag moulding peculiar to Norman architecture. See CHEVRON.

DANZIG TIMBER. See PINUS SYLVESTRIS, p. 116, 117.

DAY.—One of the divisions of a window contained between two mullions. In this sense, the same as *bay*.

DE LORME.—System of roofing by hemicycles described, p. 144.

DEAD SHORE.—An upright piece of timber built into a wall which has been broken through.

DEAFENING.—Anything used to prevent the passage of sound in floors or partitions. The term used in Scotland as synonymous with *pugging*. See p. 150.

DEAFENING-BOARDING.—Sound-boarding, or that on which pugging or deafening is laid. See p. 151.

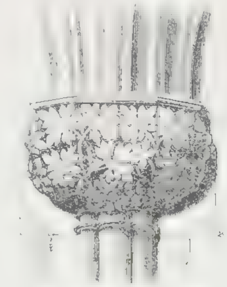
DEAL.—The usual thickness of deals is 3 inches and width 9 inches. The standard thickness is $1\frac{1}{2}$ inch and the standard length 12 feet.—*Whole deal*, that which is $1\frac{1}{4}$ inch thick; *slit deal*, half that thickness.

DECASTYLE.—A portico or colonnade of ten columns.

DECORATED STYLE.—The second of the Pointed or Gothic styles of architecture used in this country. It was developed from the Early English at the end of the thirteenth century, and gradually merged into the Perpendicular during the latter part of the fourteenth. This style is usually considered the complete and perfect development of Gothic architecture, which in the Early English was not fully matured, and in the Perpendicular began to decline. The most characteristic feature of this style is to be found in the windows, the tracery of which is always either of geometrical figures, circles, quatrefoils, &c., as in the earlier examples,

York Cathedral, West Front.

or flowing, wavy lines, as in later specimens. The arches are not so lofty and the pillars not so slender as in the Early English, and the detached shafts are only used in the early part of the period. The equilateral form prevails both for arches and windows, and the vaulting, and consequently the roofs, are not of so high a pitch as in the preceding style. The buttresses are large and projecting, frequently ornamented with canopied niches containing figures of saints, and usually terminated in richly crocketed pinnacles. Canopies, either straight-sided or of the ogee form, are much used over windows, doors, and porches. They often project, and are ornamented with rich and large finials and crockets. The doors and porches are deeply recessed, and very richly ornamented with mouldings and foliage, and have frequently also niches containing figures of saints or subjects from the Scriptures. The doorways in the west front of York Cathedral are the finest examples we have of this kind, and the front itself is considered by Rickman to be "nearly, if not quite, the finest west front in the kingdom." The upper part of the towers is in the Perpendicular style, showing the transition from one style to the other during the progress of the building. Another characteristic feature of the Decorated style is the foliage, in which natural forms are imitated, and drawn with the greatest freedom and elegance. The capitals differ in several important features from those of the Early English. In the latter the foliage generally rises from the neck moulding, on



Decorated Capital, Selby, Yorkshire

stiff stems, and curls over under the bell of the capital; but in the Decorated it is generally carried round in the form of a wreath, making a complete ball of leaves.

DECORATION.—Anything which adorns and enriches an edifice, as vases, statues, paintings, festoons, &c.

DEMI-RELIEVO.—A species of sculpture in relief, in which one-half of the figure projects from the plane of the stone or other material from which it is carved. It is also called *mezzo-rilievo*.

DENTILE, DENTILS.—Ornaments in the form

Dentils.

of little cubes or teeth, used in the bed-moulding of Ionic, Corinthian, and Composite cornices.

DENTILLED, DENTICULATED.—Having dentils

DERBY.—A two-handed float. See FLOAT.

DESCRIPTIVE CARPENTRY. INTRODUCTION, p. 76.

DESCRIPTIVE GEOMETRY. See STEREOTOMY.

DIAGLYPHIC.—A term applied to sculpture, engraving, &c., in which the objects are sunk below the general surface.

DIAGONAL. A right line drawn from angle to angle of a four sided figure.

DIAGONAL SCALE.—Construction and use of, p. 35.

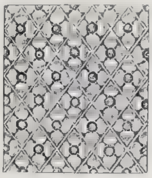
DIAMETER.—1. A right line passing through the centre of a circle or other curvilinear figure, terminated by the circumference, and dividing the figure into two equal parts. Whenever any point of a figure is called a centre, any straight line drawn through the centre, and terminated by opposite boundaries, is called a *diameter*. And any point which bisects all lines drawn through it from opposite boundaries is called a *centre*. Thus, the circle, the conic sections, the parallelogram, the sphere, the cube, and the parallelopiped, all have centres, and by analogy *diameters*. In architecture, the measure across the lower part of the shaft of a column, which being divided into 60 parts, forms a scale by which all the parts of the order are measured. The 60th part of the diameter is called a minute, and 30 minutes make a module. —2. A right line passing through the centre of a piece of timber, a rock, or other object, from one side to the other; as, the *diameter* of a tree or of a stone.

DIAMOND FRET.—A decorated moulding

Diamond Fret

consisting of fillets intersecting each other, so as to form diamonds or rhombuses; used in Norman architecture.

DIAPER.—Ornament of sculpture in low relief, sunk below the general surface, or of painting



Diaper, Westminster Abbey

or gilding, used to decorate a panel or other flat recessed surface.

DIASTYLE.—The space between columns when it consists of three diameters.

DICOTYLEDONOUS OR EXOGENOUS TREES.—General characteristics of, p. 95.

DIE.—The cubical part of a pedestal, between its base and cornice; a dado.

DIGLYPH.—A tablet with two furrows or channels.

DIMENSIONS.—Method of taking, p. 67.

DIMENSIONS OF THE TIMBERS IN A ROOF.—Rules for calculating the, p. 137.

DIMINUTION OF COLUMNS, p. 134.

DIPTERAL.—A building having double wings.

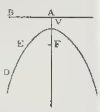
DIPTEROS.—A double-winged temple.

DIRECTING PLANE.—In perspective, a plane passing through the point of sight parallel to the plane of the picture.

DIRECTING POINT.—In perspective, the point where any original line meets the directing plane.

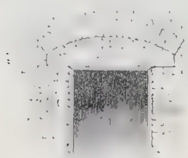
DIRECTORS, OR TRIANGULAR COMPASSES, p. 33.

DIRECTRIX.—A line perpendicular to the axis of a conic section, to which the distance of any point in the curve is to the distance of the same point from the focus in a constant ratio; also the name given to any line, whether straight or not, that is required for the description of a curve. Thus A B is the directrix of the parabola V E D, of which F is the focus.



DISCHARGE.—To transfer pressure from one point to another.

DISCHARGING ARCH.—An arch formed in the substance of a wall, to relieve the part below



Discharging Arch

it of the superincumbent weight. Such arches are commonly used over lintels and flat-headed openings.

DISEASES OF TREES, p. 96.

DISHED.—Formed in a concave.—*To dish out*, to form coves by wooden ribs.

DISTANCE, Point of.—In perspective, that point in the horizontal line which is at the same distance from the principal point that the eye is. See p. 230.

DISTRIBUTION.—The dividing and disposing of the several parts of a building, according to some plan or to the rules of the art.

DIVIDERS.—Instructions in the use of, p. 31.

DIVISIONS OF A SPHERICAL VAULT.—To determine the heights of, p. 83.

DIVISIONS OF THE RADIAL PANELS OF A CYLINDRICAL VAULT.—To determine, p. 83.

DOCK-GATES.—Illustrations and descriptions of, p. 177.

DODECAHEDRON.—A solid figure, consisting of twelve equal sides.—To find the superficial area of a dodecahedron. Multiply the *square* of the linear side by 20·6457788, and the product will be the surface.—To find the solid contents of a dodecahedron. Multiply the *cube* of the linear side by 7·6631189, and the product will be the cubical contents.

DODECAHEDRON.—To construct the projections of a dodecahedron, p. 54, 55.

DODECASTYLE.—A portico having twelve columns in front.

DOG-LEGGED STAIRS, p. 196.

DOG'S-TOOTH MOULDING.—An ornamental member, very characteristic of Early English architecture. It has no resemblance to a *dog's-tooth*, and is often called *tooth-ornament* (see that term).

DOME.—The hemispherical cover of a building; a cupola. See p. 82, and Plates XIII.–XV.

DOME, Oblong-surbased, on a rectangular plan, p. 82.

DOME, Surbased, on an octagonal plan, p. 82.

DOMES.—Definition of, p. 82.

DOMES.—Manner of dividing into compartments and caissons or coffers, p. 82.

DOMES.—To find the coverings of various kinds of, p. 75, 76, Plate IV.

DOMES AND SPHERICAL VAULTS.—To divide into compartments and caissons, p. 82.

DOMICAL.—Related to, or shaped like a dome or tholus. See CUPOLA.

DOMICAL ROOF.—Construction of, Plate XXXIV. p. 145.

DOOR.—1. An opening or passage by which persons enter into a house or other building, or into any room, apartment, or closet.—2. The closure of the door; the frame of boards or any piece of board usually turning on hinges, which shuts the opening of the door, as above defined.

DOOR.—Suspended by pulleys to an iron rail, p. 187.

DOOR-CASE.—The frame which incloses a door.

DOOR-NAIL.—The nail or knob in ancient doors on which the knocker struck.

DOOR-POST.—The post of a door.

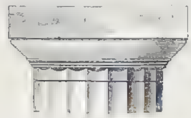
DOOR-STOPS.—Pieces of wood against which the door shuts in its frame

DOORS.—Various kinds of, p. 187.

DOORWAY.—The entrance into a building or an apartment. The forms and designs of doorways partake of the characteristics of the different classes of architecture. In the edifices of the middle ages much attention was bestowed on the design and adornment of the doorways.

DOORWAY-PLANE.—The plane frequently found between the door properly so called, and the larger opening within which it is placed. The doorway-plane was often richly ornamented with sculpture, &c.

DORIC ORDER.—The earliest and simplest of the three Greek orders. It may be divided into three parts, stylobate, column, and entablature. The stylobate is from two-thirds of a diameter to a whole diameter in height, and is divided into three equal steps or courses, which recede gradually the one above from the one below it, and the column rests on the upper step, without the intervention of any moulding. The column varies from four to six diameters in height, including the capital, which, with its necking, in this case a sunk channel, is rather less than half a diameter. The shaft of the column diminishes in a slightly curved line from its base to the hypotrachelium or necking, where its diameter is reduced from two-thirds to four-fifths of the lower diameter. The shaft is divided into flutes, generally twenty in number. They are usually segments of circles meeting in an arris. The capital consists of the necking, an echinus or ovolo, and an abacus, corbelled out below by three or four rings, or annulets, which encircle the top of the column. The entablature varies from one diameter and three-quarters to more than two diameters in height. Four-fifths of this height is generally equally divided between the architrave and frieze, and the remaining fifth given to the cornice. As a general rule, the architrave projects so as to be nearly in a line with the lower diameter; four or five sixths of its height is given to a broad face, and the remainder to the tænia, which is a continuous fillet, and the regula, a small fillet attached to it in lengths equal to the width of the triglyphs. The frieze is divided into triglyphs and metopes. The triglyphs are nearly a half diameter in width, and the metopes are generally an exact square, and in ancient examples seem invariably to have been charged with sculptures, and, indeed, the introduction of sculpture may be said to be essential to this order. There is invariably a triglyph placed on the exterior angle of the frieze, and not over the centre of the column, as in the Roman-Doric. The frieze has a fascia at top, projecting slightly and breaking round the triglyphs. The cornice is divided vertically into four parts—one of these is given to a square fillet with mouldings below it, forming the crowning member, two are given to the corona, and one to a narrow sunk face below it, with the mutules and their guttæ. There is a mutule over every triglyph, and one over every metope. All the curves of the mouldings in this order are either parabolic or hyperbolic. The Grecian-Doric order, at its best period, is one of the



Grecian-Doric Capital.

most beautiful inventions of architecture—strong and yet elegant, graceful in outline and harmonious in all its forms, imposing when on a great scale, and pleasing equally, when reduced in size, by the exquisite simplicity of its parts.

THE ROMAN-DORIC.—The ancient example of this order in the theatre of Marcellus at Rome may be regarded as a deteriorated imitation of the Grecian-Doric. The column consists of a shaft and capital, but has no base. It is eight diameters high, and diminishes one-fifth of its diameter. The capital is four-sevenths of a diameter in height. The crown mouldings and corona being destroyed, the exact height of the entablature cannot be exactly ascertained; but from analogy, it may be assumed to have been two diameters. The architrave is one-fourth of this, or half a diameter; the frieze is two-fifths of the whole height. The triglyphs are placed over the centres of the columns. The width of the metopes is equal to the height of the frieze without its fascia.

The Roman-Doric, as executed by the Italian architects, is very different from this ancient example. They introduced a base to the column, sometimes a large torus and sometimes the Attic base, and improved the proportions of the parts. The shaft of the column, as designed by Palladio, is 8 diameters in height; of this half a diameter is given to the base and 32 minutes to the capital. The entablature is two diameters in height. The architrave, including the tænia, is half a diameter, the frieze, exclusive of the fascia, is three-fourths of a diameter, and the cornice also three quarters. The shaft is sometimes fluted, the flutes being twenty in number. The necking of the capital is ornamented. The triglyph is over the centre of each column, the metopes are square and ornamented with shields, pateræ, or ox-skulls garlanded with acorns. Over each triglyph is a mutule, whose guttæ are sunk in its soffit, and the soffit of the cornice between the mutules has sunk panels, ornamented in various ways. The curves of the mouldings are all portions of circles. When a pedestal is used it is made $2\frac{6}{13}$ diameters in height.

DORMANT, DORMANT-TREE, DORMAR.—A summer, sommer, sommier, or sleeper; a beam.

DORMER-WINDOW.—A window in the sloping side of a roof, with its casement set vertically. When the window lies in the plane of the roof, it is called a *skylight*.

DORSE.—A canopy.

DOUBLE-JOISTED FLOOR.—A floor with binding and bridging joists. See p. 151, illustration, Fig. 2, Plate XLII.

DOUBLE-VAULTS.—One vault built over

Double-Vaults.
Dome of San Pietro in Montorio, Rome.

another, with a space between the convexity of the one and the concavity of the other. It is used in

domes or domical roofs when they are wished to present the appearance of a dome both externally and internally, and when the outer dome, by the general proportions of the building, requires to be of a greater altitude than would be in just proportion if the interior of its concave surface were visible. The upper or exterior vault is therefore made to harmonize with the exterior, and the lower vault with the interior proportions of the building.

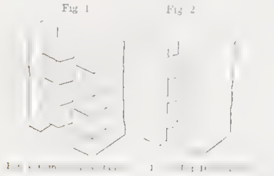
DOUBLE-MARGINED.—As double-margined doors. See p. 186.

DOUBLE SCALES.—The sector, construction and use of, p. 36.

DOUBLES.—In slating, slates measuring 1 foot 1 inch by 6 inches.

DOVE-TAIL.—The manner of fastening boards and timbers together, by letting one piece into the

Fig 1 Fig 2



other, in the form of a dove's tail spread or a wedge reversed, so that it cannot be drawn out in the direction of its fibres. See illustration of Dovetailing in Carpentry, Plate XXXIX. Fig. 16.

DOVE-TAIL MOULDING.—A moulding decorated with running bands in the form of dove-

tails, used in Norman architecture. It is sometimes called *triangular frette*.

DOVE-TAILING, p. 149.

DOWEL, *v.*—To fasten boards together by pins inserted in their edges. See p. 182.

DOWELLING.—Described, p. 182.

DRAGON-BEAM, DRAGON-PIECE.—A beam or piece of timber bisecting the angle formed by the meeting of the wall plate of two sides of a building, used to receive and support the foot of the hip-rafter.

DRAM-TIMBER. See PINUS SYLVESTRIS, p. 116, 117.

DRAUGHT.—1. In masonry, a line on the surface of a stone hewn to the breadth of the chisel.

2. In carpentry and joinery, when a tenon is to be secured in a mortise by a pin passed through both pieces, and the hole in the tenon is made nearer the shoulder than to the cheeks of the mortise, the insertion of the pin *draws* the shoulder of the tenon close to the cheeks of the mortise, and it is said to have a *draught*.

DRAW-BORE.—A hole pierced through a tenon, nearer to the shoulder than the holes through the cheeks from the abutment in which the shoulder is to come into contact.

DRAW-BORE PIN.—A joiner's tool, consisting of a solid piece or pin of steel, tapered from the handle, used to enlarge the pin-holes which are to secure a mortise and tenon, and to bring the shoulder of the rail close home to the abutment on the edge of the style. When this is effected, the draw-bore pin is removed, and the hole filled up with a wooden peg.

DRAWBRIDGE.—A bridge which may be drawn up or let down to admit of or to hinder communication between its points of support. The name is applied generally to all bridges which can be drawn from their position, either by turning horizontally or vertically round an axis, or by sliding. See example of Sliding-bridge, Plate XLVIII. Fig. 1.

DRAWING.—General remarks on, p. 45.

DRAWING-BOARDS.—Useful sizes and construction of, p. 43.

DRAWING-INSTRUMENTS.—Construction and use of, p. 31–45.

DRAWING INSTRUMENTS.—Management of, p. 45.

DRAWING-KNIFE.—An edge tool, used to make an incision into the surface of wood, along the path the saw is to follow. It prevents the teeth of the saw tearing the surface of the timber.

DRAWING-PAPER.—Dimensions and quality of, p. 42.

DRAWING PAPER.—How to stretch on the drawing-board, p. 43.

DRAWING-PEN, p. 42.

DRAWING-PINS, p. 45.

DRESSINGS.—All mouldings which are applied as ornaments, and project beyond the naked of the work.

DRIFT.—A piece of iron or steel rod used in driving back a key of a wheel, or the like, out of its place, when it cannot be struck directly with the hammer. The drift is placed against the end of the key, or other object, and the strokes of the hammer are communicated through it to the object to be displaced.

DRIP.—The edge of a roof; the eaves; the corona of a cornice.

DRIPSTONE.—The label moulding in Gothic architecture, which serves as a canopy for an open-

Dripstone, Westminster Abbey

ing, and to throw off the rain. It is also called *weather-moulding* and *water-table*.

DROP-ARCH. To draw, p. 29.

DROPS.—Small cylinders or truncated cones, used in the mutules of the Doric cornice, and in the member immediately under the triglyph of the same order. See woodcut, GUTTÆ.

DROVING.—In stone cutting, the same as *random-tooling* (which see).

DROVING AND STRIPING.—In stone-cutting, droving and striping is used when it is wished to relieve a large surface by the character of the work, in the absence of breaks, openings, or ornaments. The stone is prepared and draughted as in nidging, and then with a chisel about one-fourth of an inch wide, shallow parallel channels are run in the direction of the length of the stone, at distances apart of about 1½ inch. This gives a very neat and finished air to a building, but it is expensive, and is never used where economy is an object.

DRUM.—1. The stylobate or vertical part under a cupola or dome.—2. The solid part of the Corinthian and Composite capitals; called also *bell, vase, basket*.

DRUXY.—An epithet applied to timber with decayed spots or streaks of a whitish colour in it.

DRYS.—In masonry, fissures in a stone intersecting it at various angles to its bed, and unfitting it for sustaining a load.

DUCHESSES.—In slating, slates measuring 2 feet by 1 foot.

DURAMEN.—The heart-wood of a tree.

DWANGS.—The Scotch term for struts inserted between the joists of a floor or the quarterings of a partition, to stiffen them.

DWARF-WALLS.—Walls of less height than a story of a building. The term is generally applied to the low walls built under the ground-floor, to support the sleeper joists.

E.

EARLY ENGLISH ARCHITECTURE.—The first of the Pointed or Gothic styles of architecture that prevailed in this country. It succeeded the Norman towards the end of the twelfth century, and gradually merged into the Decorated at the end of the thirteenth. One of the leading peculiarities in this style is the form of the windows, which are narrow in proportion to their height, and terminate in a pointed arch, resembling the blade of a lancet. Throughout the early period of the style, they are very plain, particularly in small churches, but in cathedrals and other large buildings, the windows, frequently combined two or more together, are carried to a great height, are richly and deeply moulded, and the jambs ornamented with slender shafts. On the eastern and western fronts of small churches the windows are often combined in this manner, with a circular window above and a richly moulded door below; but in large buildings there is often more than one range of windows, and the combinations are very various. Though separated on the outside, these lancets are in the interior combined into one design by a wide splaying of the openings, thus giving the first idea of a compound window. The doorways are in general pointed, and in rich buildings sometimes double; they are usually moulded, and enriched with the tooth ornament. The buttresses are often very bold and prominent, and are frequently carried up to the top of the building with but little diminution, and terminate in acutely-pointed pediments, which, when raised above the

North-west Transept, Beverley Minster

parapet, produce in some degree the effect of pinnacles. In this style, likewise, flying buttresses were first introduced (see FLYING-BUTTRESS), and the buttresses themselves much increased in projection from the comparative lightness of the walls, which required some counter support to resist the outward pressure of the vaulting. The roof, in the Early English style, appears always to have been high pitched. In the interior the arches are usually lancet-shaped, and the pillars often reduced to very slender proportions. As if to give still greater lightness of appearance, they are frequently made up of a centre pillar, surrounded by slight detached shafts, only connected with the pillar by their capitals and bases, and bands of metal placed at intervals. These shafts are generally of Purbeck marble, the pillar itself being of stone, and, from their extreme slenderness, they appear as if quite inadequate to support the weight above them. Some of the best examples are to be seen in Salisbury Cathedral. The architects of this style carried their

Early English Capital, Salisbury Cathedral

ideas of lightness to the utmost limits of prudence, and their successors have been afraid to imitate their example. The abacus of the capitals is generally made up of two bold round mouldings, with a deep hollow between. The foliage is peculiar, generally very gracefully drawn, and thrown into elegant curves; it is usually termed *stiff-leaved*, from the circumstance of its rising with a stiff stem from the neck-mould of the capital. The trefoil is commonly imitated, and is very characteristic of the style. The mouldings of this style have great boldness, and produce a striking effect of light and shade. They consist chiefly of rounds separated by deep hollows, in which a peculiar ornament, called the *dog's-tooth*, is used, whenever ornament can be introduced. This ornament is as characteristic of the Early English as the zigzag is of the Norman.

EARTH-TABLE.—The course of stones in a wall seen immediately above the surface of the ground, now called the *plinth*. It is also termed *grass-table* and *ground-table*.

EAVES.—That part of a roof which projects beyond the face of a wall.

EAVES-BOARD; called also EAVES-CATCH and EAVES-LATH.—An arris-fillet nailed across the rafters at the eaves of a roof, to raise the slates a little.

EAVES-GUTTER.—A gutter attached to the eaves.

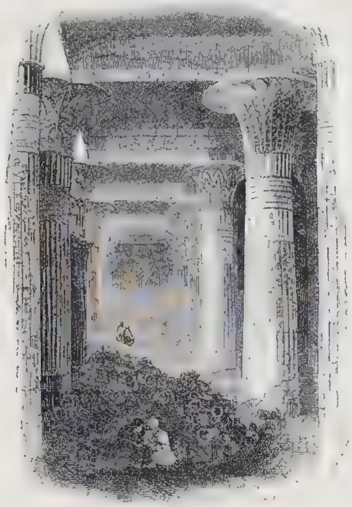
ECHINUS.—An ornament in the form of an egg, peculiar to the ovolo or quarter-round mould-

Echinus

ing; whence this moulding is sometimes called *echinus*.

EGG-AND-ANCHOR, EGG-AND-DART, EGG-AND-TONGUE. See ANCHOR and ECHINUS.

EGYPTIAN ARCHITECTURE.—The style of building which prevailed in ancient Egypt, and the remains of which, as exhibited in the pyramids,



Interior of the Temple of Esneh.

tombs, and ancient temples scattered over that country, alike excite our wonder, and attest the magnificence and advanced civilization of the period to which they belong. Its remains are probably the most ancient of any in the world, the only buildings that may possibly vie with them in point of antiquity being the rock-cut temples and other monuments of India. The characteristics of Egyptian architecture are solidity, boldness, and originality; the object being to fill the mind of the spectator with astonishment and awe. The columns are numerous, close, and very large, being sometimes ten or twelve feet in diameter. They are generally without bases, and had a great variety of capitals, from a simple square block ornamented with hieroglyphics or faces, to an elaborate composition of palm-leaves, bearing a distant resemblance to the Corinthian capital. The shafts are either plain or worked into reeds or flutes, and frequently are constructed to represent various plants, such as the lotus, the date-palm, or the papyrus. The entablature is very simple, consisting of a plain architrave, surmounted by a large torus, and a large overhanging concave moulding, which serves as a cornice. The roofs of the temples were formed by large blocks of stone, extending from wall to wall or from column to column, and not unfrequently the roof was wholly absent. In the construction of the portico of the temples the greatest magnificence was displayed. It was frequently approached by an avenue of sphinxes and other sculptures, extending to a considerable distance, and the doorway was flanked by two towers of a peculiar shape, broad in front and

Egyptian Capital, Denderah

narrow at the sides, with the walls sloping back at a slight angle from the perpendicular. The walls, pillars, and interior of the temple generally, were covered with a profusion of hieroglyphics, pictures, and symbolical figures. Many of the pictures still display great brilliancy of colouring, the dryness of the climate having preserved them nearly intact after so great a lapse of time. No use appears to have been made of wood, and the stones employed in the construction of the columns were of the most gigantic dimensions. Another prominent characteristic of Egyptian architecture is the absence of the arch, no specimen of which occurs among their ancient monuments.

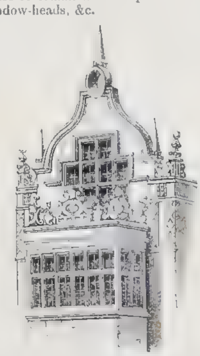
EIDOGRAPH.—A form of the pantagraph, for copying, enlarging, or reducing drawings, invented by Professor Wallace of Edinburgh.

ELBOW-LINING.—The lining of the elbows of a window. See p. 188.

ELBOWS.—The upright sides which flank any panelled work, as in windows below the shutters.

ELEVATION.—A geometrical delineation of any object according to its vertical and horizontal dimensions, without regard to its thickness or projections; the front or any other extended face of a building.

ELIZABETHAN ARCHITECTURE.—A name given to the impure architecture which prevailed in the reigns of Elizabeth and James I., when the worst forms of Gothic and debased Italian were combined together, producing singular heterogeneousness in detail, but wonderful picturesqueness in general effect. Its chief characteristics are windows of great size, both in the plane of the wall and deeply embayed, and galleries of great length, combined with a profuse use of ornamental strap-work in the parapets, window-heads, &c.



Elizabethan Window, Rushton Hall, cir. 1590.

ELLIPSE, Description of the, p. 22.

ELLIPSE, to draw, when the major and minor axes are given, Prob. LXXXV. p. 22, and Prob. LXXXVI. p. 23.

ELLIPSE, the, to draw, with the trammel, Prob. LXXXVII. p. 23.

ELLIPSE, the, to draw, on the method of the trammel, without using the instrument, Prob. LXXXVIII. p. 24.

ELLIPSE, to describe, by means of a string, Prob. LXXXIX. p. 24.

ELLIPSE, to draw with the compass a figure approaching the, Prob. XCIII. and XCIV. p. 25, and Prob. XCVI. p. 26.

ELLIPSE.—To find the circumference of an ellipse.—Rule: Multiply half the sum of the two diameters by 3·1416.—To find the area of an ellipse. Rule: Multiply the largest diameter by the shortest, and the product by ·7854.

ELLIPSES, to draw, by intersecting lines, Prob. XC. and XCI. p. 24.

ELLIPSOID, an, to describe the section of, p. 68, Plate I. Fig. 8.

ELLIPSOIDAL VAULTS.—To determine the caissons of, p. 83.

ELLIPTICAL-DOMICAL PENDENTIVE, p. 81.

ELM, The.—Properties and uses of, p. 110.

ELM, Wych, p. 111.

ELM, Rock, p. 111.

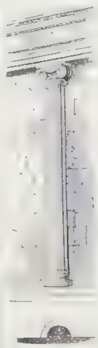
ELM, Dutch, p. 111.

ELM, Twisted, p. 111.

EMBATTLEMENT, OR BATTLEMENT.—An indented parapet, belonging originally to military works, the indents, crenelles, or embrasures being used for the discharge of missiles. It was afterwards adopted extensively as a decoration in mediæval architecture.

EMBOSS, *v.*—To form bosses or protuberances; to cut or form with prominent figures.

EMBRASURE.—An opening in a wall, splaying or spreading inwards. The term is usually applied to the indent or crenelle of an embattled parapet.



Engaged Column.

EMY'S LAMINATED ROOFS, p. 141.

ENCARPA, ENCARPUS.—A festoon of fruit or flowers on a frieze or capital. See FESTOON.

ENDOGENOUS PLANTS. See ENDOGENS.

ENDOGENS.—Plants whose stems are increased by the development of woody matter towards the centre, instead of at the circumference, as in exogens. To this class belong palms, grasses, rushes, &c. Stems of this sort have no distinct concentric layers or medullary rays.

ENDOGENS.—General characteristics of, p. 93.

ENGAGED COLUMN.—A column attached to a wall, so that part of it is concealed. Engaged columns have seldom less than a quarter, or more than a half of their diameter in the solid of the wall.

ENGLISH BOND.—That disposition of bricks in brick-work which consists of courses of headers and stretchers alternately. The figures show the first and second courses of a 14-inch wall. A is a

course consisting of a row of stretchers *a a*, and headers *b b*; and B, the next succeeding course, shows the disposition of these reversed.

ENLARGING AND DIMINISHING MOULDINGS.—Method of, p. 181.

ENNEAGON.—A polygon, with nine sides or nine angles.

ENRICH.—To adorn with carving or sculpture.

ENSTYLE.—An intercolumniation of two and a quarter diameters.

ENTABLATURE.—That part of an order which lies upon the abaci of the columns. It consists of three principal divisions—the architrave, the frieze, and the cornice. See woodcut, COLUMN.

ENTAIL.—The more delicate and elaborate parts of carved work.

ENTASIS.—A swelling; the curved line in

which the shaft of a column diminishes; the swelling in the middle of a baluster. See Figs. 2, 3, and 4, Plate LXXII.

ENTERCLOSE.—A passage between two rooms.

ENTRESOL.—A low story between two other stories.

EPISTYLIUM, EPISTYLE.—An ancient name for the architrave.

EQUILATERAL ARCH, to draw, p. 28.

EQUILATERAL TRIANGLE, to describe, Prob. XI. p. 7.

EREMACAUSIS, or SLOW COMBUSTION or OXIDATION, the cause of decay in timber. See p. 105.

EREMACAUSIS, remedies for, p. 105.

ESCAPE.—That part of a column where it springs out of the base; the apophyge; the congé.

ESCUTCHEON.—1. A shield for armorial bearings.—2. A plate for protecting the keyhole of a door, or to which the handle is attached.

ESTRADE.—An elevated part of the floor of a room; a public room.

EXCRESCENCES IN TREES, p. 97.

EXEDRA, EXHEDRA.—In ancient architecture, the name given to vestibules or apartments in public buildings where the philosophers disputed, and also to apartments or vestibules in private houses used for conversation. In mediæval architecture, the term is sometimes applied to the porch of a church, especially to the galilee or western porch. The apsis, too, was sometimes termed the *exedra*.

EXFOLIATION of the bark of trees, p. 97.

EXOGEN.—A plant whose stem increases by development of woody matter towards the outside. To this class belong all our timber trees.

EXOGENS.—General characteristics of, p. 94.

EXPANDING CENTRE-BIT.—A hand-instrument, chiefly used for cutting out discs of leather and other thin material, and for making the margins of circular recesses. It consists of a central stem *a*, and point *b*, mounted on a transverse bar *c*, which carries a cutter *d* at one end, and is adjustable for radius. The arm *c* being carried round the fixed points *a* and *b*, the cutter *d* describes a circle of which the radius is the distance *b d*.

EXTRADOS.—The exterior curve of an arch. See ARCH.

EYE.—A general term applied to the centre of anything, as the eye of a volute, of a dome.

F.

FAÇADE.—The face or front of an edifice.

FACE-MOULD.—One of the patterns for marking the board or plank out of which the hand-rails for stairs and other works are to be cut. See STAIRCASES and HAND-RAILING, in text.

FACETS, FACETTES.—Small projections between the flutings of columns.

FACIA. See FASCIA.

FACING.—1. The thin covering of polished stone, or of plaster or cement, on a rough stone or brick wall.—2. The wood-work which is put as a border round apertures, either for ornament or to cover and protect the junction between the frames of the apertures and the plaster.—3. Sometimes in joinery used synonymously with *lining*.

FACTABLE.—The same as *coping*.

FAGUS SYLVATICA.—The beech tree. For description, see p. 111.

FALDSTOOL.—A kind of stool placed at the south side of the altar, at which the Kings of England kneel at their coronation.—2. A small desk, at which the Litany is enjoined to be sung or said; sometimes called a *Litany stool*.—3. The chair of a bishop, inclosed by the railing of the altar.—4. An arm-chair; a folding-chair.

FALLING MOULDS.—The two moulds which, in forming a hand-rail, are applied, the one to its convex, and the other to its concave vertical side, in order to form the back and under-surface, and finish the squaring.

FALLING MOULD IN HAND-RAILING, to construct, p. 201.

FALLING STYLE.—That style of a gate or door in which the lock, latch, or other fastening, is placed. See GATES, p. 176.

FALSE ATTIC.—An architectural finish, bearing some resemblance to the Attic order, but without pilasters or balustrade. It is used to crown a building and to receive a bas relief or inscription.

FALSE ROOF.—The open space between the ceiling of an upper apartment and the rafters of the roof.

FAN LIGHT.—Properly a semicircular window over the opening of a door, with radiating bars in the form of an open fan, but now used for any window over a door.

FAN-TRACERY VAULTING.—The very complicated mode of roofing, much used in the Perpendicular style, in which the vault is covered by

Fan-tracery, North Aisle, St George's Chapel, Windsor.

ribs and veins of tracery, of which all the principal lines have the same curve, and diverge equally in every direction from the springing of the vault, as in Henry VII.'s Chapel, Westminster, and St. George's Chapel, Windsor.

FASCIA.—1. A band or fillet.—2. Any flat member with a little projection, as the band of an architrave.—3. In brick buildings, the jutting of the bricks beyond the windows in the several stories except the highest.

FASTIGIUM.—The summit, apex, or ridge of a house or pediment.

FEATHER BOARDING.—A covering of boards, in which the edge of one board overlaps a part of the one next it. It is also called *weather-boarding*.

FEATHER-EDGED BOARDS.—Boards made thin on one edge.

FEATHERINGS, OR FOLIATIONS.—The cusps or arcs of circles with which the divisions of a Gothic window are ornamented.

FELLOE.—The outer rim of the frame of a centre or mould under the lagging or covering-boards. See p. 173.

FELLING OF TIMBER.—Different modes of procedure, p. 98.

FELLING OF TIMBER.—Comparative cost of various methods, p. 99.

FELLING OF TIMBER.—Proper season for the operation, p. 99.

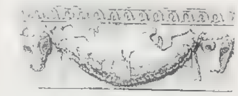
FELT GRAIN.—Timber split in a direction crossing the annular layers towards the centre. When split conformably with the layers it is called the *quarter grain*.

FEMUR.—In architecture, the interstitial space between the channels in the triglyph of the Doric order.

FENDER-PILES.—Piles driven to protect work, either on land or water, from the concussion of moving bodies.

FENESTRAL.—A small window. Used also to designate the framed blinds of cloth or canvas that supplied the place of glass previous to the introduction of that material.

FESTOON.—A sculptured ornament in imitation of a garland of fruits, leaves, or flowers, suspended between two points. The garland is of the greatest size in the middle, and diminishes gradually to the points of suspension, from which the ends generally hang down. The festoon, in architecture, is sometimes composed of an imitation of drapery similarly disposed, and frequently of an



assemblage of musical instruments, implements of war or of the chase, and the like, according to the purpose to which the building it ornaments is appropriated.

FILLET.—A small moulding, generally rectangular in section, and having the appearance of a narrow band. It has many synonymes.—In carpentry and joinery, any small scantling less than a batten.

FILLISTER.—A kind of plane used for grooving timber or for forming rebates.

FINE STUFF.—Plaster used in common ceilings and walls for the reception of paper or colour.

FINIAL.—The ornamental termination to a

pinnacle, consisting usually of a knot or assemblage of foliage. By old writers finial is used to denote not only the leafy termination, but the whole pyramidal mass.

FINISHING COAT.—In plastering, the last coat of stucco-work where three coats are used.

FINLAND TIMBER. See PINUS SYLVESTRIS, p. 116, 117.

FIR TREE. See description and uses, p. 116.

FIRE-PLACE.—The lower part of a chimney which opens into the room or apartment, and in which the fuel is burned.

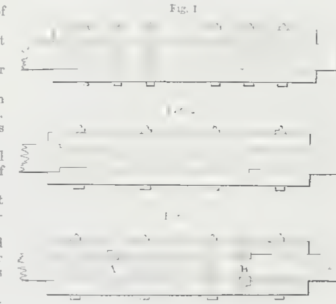
FIRMER.—A paring chisel. See CHISEL.

FIRRINGS.—Pieces of wood nailed to any range of scantlings to bring them to one plane, applied generally to the pieces added to joists which are under the proper level for laying the floor. Called also *furrings*. See p. 185.

FIRST COAT.—The first plaster coat laid on laths is so called when only two coats are used. When three coats are used, it is called the *pricking-up coat*. In brick-work, the first of two-coat work is called *rendering*, and the first of three-coat work *roughing up*.

FISHING, FISHED BEAM.—A built beam, composed of two beams placed end to end, and

Fig. 1



secured by pieces of wood covering the joint on opposite sides. Fishing is performed in three diffe-

rent ways. In the first the ends of the beam are abutted together, and a piece of wood is placed on each side and secured by bolts, fig. 1. Secondly, the parts may be indented together, so as better to resist a tensile strain, as in fig. 2. Thirdly, pieces, termed *keys*, may be notched equally into the beams and the side-pieces, as at A B, fig. 3. See p. 147, 148.

FISTUCA.—An instrument for driving piles, with two handles, raised by pulleys, and guided in its descent so as that it may fall upon the head of the pile, and drive it into the ground. It is called by the workmen a *monkey*.

Flamboyant Window, Church of St. Ouen at Rouen.

FIXED OR INFLEXIBLE CENTRE, in bridge-building, p. 172.

FLAMBOYANT STYLE OF ARCHITECTURE.—A term applied by French writers to that style of Gothic architecture in France which was coeval with the Perpendicular style in Britain. Its chief characteristic is a wavy, flame-like tracery in the windows, panels, &c.; whence the name.

FLANK.—1. The side of a building.—2. The Scotch term for a valley in a roof.

FLANNING.—The splaying of a door or window-jamb internally.

FLAPS.—Folds or leaves attached to window-shutters.

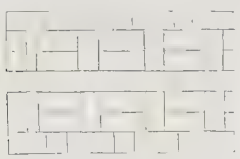
FLASHINGS.—In plumbing, pieces of lead, zinc, or other metal, used to protect the joinings where a roof comes in contact with a wall, or where a chimney, shaft, or other object comes through a roof. The metal is let into a joint or groove cut in the wall, and then folded down so as to cover and protect the joinings. When the flashing is folded down over the upturned edge of the lead of a gutter, it is termed in Scotland an *apron*.

FLAT PANELS, p. 185.

FLATTING.—A coat of paint which, from its mixture with turpentine, leaves the work *flat* or without gloss.

FLECHE.—A name for a spire when the altitude is great compared with the base.

FLEMISH BOND.—That disposition of bricks which exhibits externally alternate headers and stretchers in each course, whereas in English



bond the headers and stretchers are in alternate rows. The figure shows two courses of a 14-inch wall in Flemish bond.

FLEURON.—Foliage such as that in the centre of the abacus of the Corinthian capital. It has been defined to be such foliage as is not in direct imitation of nature.

FLEXIBLE CENTRES, p. 171.

FLIERS.—Steps of a stair which are parallel-sided; such as do not wind. See p. 196.

FLIGHT.—A series of fliers from one level to another. See p. 196.

FLOATING.—Reducing the surface of plaster-work to a plane. It is thus performed:—The whole surface of the work is divided into bays or compartments, by ledges of lime and hair, from 6 to 8 inches wide, extending from the top to the bottom of the walls, and across the whole width of the ceiling. These are termed *screeds*, and are formed at 4, 5, or 6 feet apart, by the plumb-rule and straight-edge, so as to be accurately in the same plane. They thus become gauges or guides for the rest of the work. When the screeds are thus prepared, the panels or interspaces are filled in flush with plaster, and a long float being made to traverse them, all the plaster which projects beyond is struck off, and the whole surface reduced to one plane.

FLOATS.—Plasterers' tools, consisting of straight rules, which are moved over the surface of plaster while soft, to reduce it to a plane. They are of three sorts: the *hand-float*, used by one man; the *quick-float*, used in angles; and the *derby* or *two-handed float*, which is so long, that two men are required to work it.

FLOOR.—1. That part of a building or room on which we walk. See p. 150.—2. A platform of boards, planks, or other material, laid on timbers.

FLOORING.—The whole structure of the floor-platform of a building, including the supporting timbers. The weight of flooring is estimated at from 30 to 80 lbs. per foot superficial, and floors of dwelling-houses are generally calculated to carry 150 lbs. per foot superficial, including their own weight.

FLOORING-MACHINE.—A machine for preparing complete flooring-boards with great despatch; the several operations of sawing, planing, grooving and tonguing being all carried on at the same time by a series of saws, planes, and revolving chisels.

FLOOR.—Constructed by Serlio at Bologna, in 1518, p. 153.

FLOOR of the Palace in the Wood at the Hague, p. 153.

FLOOR-TIMBERS.—The timbers on which the floor-boards are laid.

FLOORS.—Variation in the mode of construction common in Scotland, Plate XLIII. Figs. 1 and 2, p. 151.

FLOORS.—Mode of construction of, used in France, Plate XLIV. p. 152.

FLOORS.—Construction of warehouse-floors, Plate XLIII. Figs. 4–10, p. 152.

FLOORS.—Formed of a combination of small timbers, Plate XLIV. Figs. 15–17, p. 153.

FLOORS, Fire-proof, Plate XLIII. Figs. 12–14, p. 154.

FLOORS.—Rules for calculating the strength of timbers which enter into the composition of, p. 154.

FLORIATED.—Having florid ornaments; as, the *floriated* capitals of early Gothic pillars.

FLORID STYLE.—A term employed by some writers on Gothic architecture to designate that highly enriched and decorated architecture which prevailed in the fifteenth and beginning of the sixteenth century. It is often called the *Tudor style*, as it prevailed chiefly in the Tudor era.

FLUE.—A passage for smoke in a chimney, leading from the fireplace to the top of the chimney, or into another passage; as, a chimney with four *flues*. Also, a pipe or tube for conveying heat to water, in certain kinds of steam-boilers. The same name is given to passages in walls for the purpose of conducting heat from one part of a building to the others.

FLUING.—Expanding or splaying, as the jambs of a window.

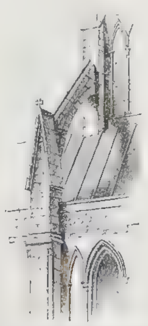
FLUSH.—A term applied to surfaces which are in the same plane.—*To flush a joint*, is to fill it until the filling material is in the plane of the surfaces of the bodies joined.

FLUSH PANEL, p. 185.

FLUTINGS, OR FLUTES, are the hollows or channels cut perpendicularly in columns, &c. When the flutes are partially filled by a smaller round moulding, they are said to be *cabled*. See CABLE.

FLYERS.—Steps in a flight of stairs which are parallel to each other. See FLIERS.

FLYING-BUTTRESS.—In Gothic architec-



Flying-buttress, Beverley Minster

ture, a buttress in the form of an arch springing from a solid mass of masonry and abutting against another building, to resist the thrust of an arch or of a roof. It is seen in many cathedrals; and there its office is to act as a counterpoise against the vaulting of the central pile.

FOCUS.—1. A point in which any number of rays of light meet, after being reflected or refracted; as, the *focus* of a lens.—*Virtual focus* or *point of divergence*, the point from which rays tend after refraction or reflection.—*Geometrical focus*, the point in which rays of light ought to be concentrated when reflected from a concave mirror, or refracted through a lens, the point in which they are actually found being termed the *refracted focus*. These foci are separated from one another, in proportion to the degree of spherical aberration.—2. A certain point in the parabola, ellipsis, and hyperbola, where rays reflected from all parts of these curves concur or meet. The *focus of an ellipse* is a point toward each end of the longer axis, from which two right lines, drawn to any point in the circumference, shall together be equal to the longer axis. The *focus of a parabola* is a point in the axis within the figure, and distant from the vertex by the fourth part of the parameter. The *focus of a hyperbola* is a point in the principal axis, within the opposite hyperbolas, from which, if any two lines are drawn, meeting in either of the opposite hyperbolas, the difference will be equal to the principal axis.

FOILS.—The small arcs in the tracery of Gothic windows, panels, &c., which are said to be

Trefoil. Quatrefoil. Cinquefoil.

trefoiled, quatrefoiled, cinquefoiled, and multifoiled, according to the number of arcs they contain.

FOLDED FLOORING, p. 185.

FOLIATION.—The use of small arcs or foils in forming tracery.

FOMERELL.—A lantern-dome or cover.

FONT.—A vessel employed in Protestant churches to hold water for the purpose of baptism, and in Catholic churches used also for holy water.

Font, Colebrooke

There are a great many fonts in England, curious both for their antiquity and their architectural designs. In the Decorated style, their form is usually octagonal, sometimes hexagonal; and in the Perpendicular style, the octagonal form is almost invariably used.

FOOT-PACE.—A landing or resting place at the end of a flight of steps. If it occurs at the angle where the stairs turn, it is called a *quarter-pace*.

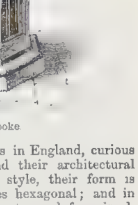
FOOT-STALL.—The plinth or base of a pillar.

FOOTING.—A spreading course at the foundation of a wall. The footings appear like steps, as in the figure.

FOOTING-BEAM.—The tie-beam of a roof.

FORE-PLANE.—The first plane used after the saw or axe.

FORE-SHORTENING.—In perspective, the diminution which in representation a body suffers in one of its dimensions, as compared with the others, owing to the obliquity of the diminished part to the plane of the picture.



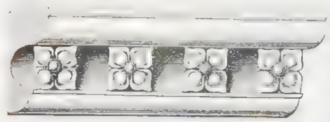
Footing of a Wall.

FORMERETS.—The arches which in Gothic groins lie next the wall, and are consequently only half the thickness of those which divide the wall into compartments.

FOUNDATIONS.—The solid ground on which the walls of a building rest; also that part of the building or wall which is under the surface of the ground.

FOUR-CENTERED ARCH, to draw, p. 29.

FOUR LEAVED FLOWER.—An ornamental member, much used in hollow mouldings, very



Four-leaved Flowers, W[illegible]

characteristic of the Decorated period of Gothic architecture.

FOX-TAIL WEDGING.—A method of fixing a tenon in a mortise, by splitting the end of the tenon beyond the mortise, and inserting a wedge. The wedge being driven forcibly in, enlarges the tenon, and renders the joint firm. When the mortise is not cut through and through, the wedge is inserted in the end of the tenon, and the tenon entered into the mortise, and then driven home. The bottom of the mortise resists the wedge, and forces it further into the tenon, which is thus made to expand, and press firmly against the sides of the mortise.

FRAME.—A term applied to any assemblage of pieces of timber firmly connected together.

FRAMED-FLOOR.—One with girders, binding-joists, and bridging-joists. See p. 151, Plate XLII. Fig. 3.

FRAMED or Bound Doors, p. 186.

FRAMING.—1. Fitting and joining in construction. See p. 146.—2. The rough timbers of a house, including beams, flooring, roofing, and partitions.

FRAXINUS.—The ash tree. See p. 112.

FREDERICKSTADT TIMBER. See p. 116, 117, Pinus sylvestris.

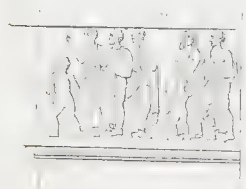
FRENCH DOORS.—Examples of, Plate LXXIV. Figs. 5 15, p. 187.

FRESCO.—A method of painting on walls, performed with water-colours on fresh plaster, or on a wall coated with mortar not yet dry. The colours, incorporating with the mortar, and drying with it, become very durable. Only as much of the wall is coated with plaster as the artist expects to finish during a day's work, and at the end of the day the portion not painted on is carefully cut off by the outline of a figure, or other well defined form, so as to conceal the joining in commencing next day's work. From difficulty of alteration when the colour is once absorbed, the greatest precision of design is necessary before commencing the work. With this view, a drawing on paper, the exact size of the work to be executed, called a cartoon, is prepared beforehand, and from it the outlines of the design are carefully traced on the wet plaster. This method of painting is very ancient. It was used by the Greeks, and in later times was much employed by the great masters of the Italian schools. It is called *fresco*, either because it is done on *fresh* plaster, or because it is used on walls and buildings in the open air.

FRET.—Work raised in protuberances. A kind of knot or meander, consisting of two fillets interlaced, used as an ornament in architecture. All the embattled, crenelled, and lozenge mouldings are frets. An *à la Grecque*.

FRETTED ROOFS.—Groined roofs, much intersected by arches.

FRIEZE.—That part of an entablature which



Sculptured Frieze, Temple on the Illys[illegible]

is between the architrave and cornice. It is a flat member, usually enriched with sculptures.

FRIEZE-PANEL.—The upper panel of a door of six or more panels. See p. 186.

FRIEZE-RAIL.—The rail next below the top rail of a door of six or more panels. See p. 186.

FRONTISPIECE.—The face of a building.

FRONTON.—A pediment.

FROST CRACKS in trees, p. 97.

FRUSTUM.—The part of a solid next the base, left by cutting off the top or segment by a plane parallel to the base; as the frustum of a cone, of a pyramid, of a conoid, of a spheroid, or of a sphere, which latter is any part comprised between two parallel circular sections; and the middle frustum of a sphere is that whose ends are equal circles, having the centre of the sphere in the middle of it, and equally distant from both ends.

FURNESS' Mortising Machine, p. 194.

FURNESS' Planing Machine, p. 193.

FURNESS' Tenoning Machine, p. 193.

FUST of a Column.—The shaft.

G.

GABLE.—The triangular end of a house or other building, from the cornice or eaves to the top.

GABLE-ROOF.—A roof open to the sloping rafters or spars, finishing against gable-walls.

GABLE-WINDOW.—A window in a gable, or a window shaped like a gable.

GABLET.—A small gable or gable-shaped decoration, frequently introduced on buttresses, screens, &c.

GAGE, or Gauge.—1. The length of a slate or tile below the lap; also the measure to which any substance is confined.—2. The quantity of plaster of Paris used with common plaster to hasten its setting.

GAIN.—1. A bevelling shoulder.—2. A lapping of timbers.—3. The cut that is made to receive a timber.

GALILEE. A small gallery or balcony, open to the nave of a conventual church, from which visitors might view processions; also a porch or portico annexed to a church, and used for various purposes.

GALLERY.—1. An apartment of much greater length than breadth, serving as a passage of communication for the different rooms of a building.—2. Any apartment whose length greatly exceeds its breadth, used for the reception of pictures, statues, &c., its use being denoted by a qualifying word, as picture-gallery, sculpture-gallery, &c.—3. A platform projecting from the walls of a building, supported on piers, pillars, brackets, or consoles, as the gallery of a church or of a theatre.—4. A long portico, with columns on one side.

GALLERY of a Church.—Framing for the, p. 150.

GARGOYLE, or Gurgoyle.—A spout in the cornice or parapet of a building, for throwing the roof water beyond the walls. Gargoyles, in classic

Gargoyle, Stony-Stratford

architecture, were ornamented with masks, and carved into the representations of heads of animals, especially of the head of the lion. In the architecture of the middle ages the gargoyle became longer, and assumed a vast variety of forms.

GARNET-HINGE.—A species of hinge, resembling the letter T laid horizontally, thus ⊢; called in Scotland a *cross-tailed hinge*.

GARRET.—1. That part of a house which is on the upper floor, immediately under the roof.—2. Rotten wood.

GARRETTING.—Inserting small splinters of stone in the joints of coarse masonry, after the walls are built. Flint walls are frequently garretted

GATES.—Dock Gates, illustrations and descriptions of, Plates LXI., LXII., and p. 177, 178.

GATES.—Park and Entrance Gates, illustrations and description of, Plate LX. and p. 177.

GATEWAY.—1. A way through the gate of some inclosure.—2. A building to be passed at the entrance of the area before a mansion.

GATHERING of the Wings.—The lower part of the funnel of a chimney.

GAUGE.—Measure; dimension.

GAUGED-ARCHES are those in which the bricks are cut and rubbed to a gauge or mould, so as to make exactly fitting joints.

GAUGED-PILES.—Large piles placed at regular distances apart, and connected by horizontal beams, called *runners* or *wale pieces*, fitted to each side of them by notching, and firmly bolted. A gauge or guide is thus formed for the *sheeting* or *filling* piles, which are driven between the wale-pieces, and fill up the spaces between the gauged-piles. Gauged piles are called also *standard piles*.

GAUGED-STUFF.—In plastering, stuff composed of three parts of putty-lime and one part of plaster of Paris.

GAVEL. See Gable.

GEFLE TIMBER. See Pinus sylvestris, p. 116, 117.

GEMMELS.—An old name for hinges.

GEOMETRICAL ELEVATION.—A drawing of the front or side of a building or any object.—The projection, on a vertical plane, of the front or side of a building or other object.

GEOMETRICAL STAIRS.—Those stairs the steps of which are supported at one end only by being built into the wall. See p. 196.

GIBLET-CHECK, or Jiblet-Check.—A term used by stone-masons in Scotland, to signify a rebate made round the opening of a doorway, forming a recess to receive a door or gate which opens outwards.

GIBS.—Pieces of iron employed to clasp together such pieces of a framing as are to be keyed, previous to inserting the keys.

GIRDER.—A main beam to support the joists of a floor. It may be in one or two pieces, plain or trussed. See Trussed Girders, p. 149 and Plate XL.

GIRDERS.—Rules to determine the strength of, p. 155.

GIRDLING Trees, to exhaust their sap before felling, p. 99.

GIRTH.—In practice, the square of the quarter girth multiplied by the length, is taken as the solid content of a tree.

GLACIS.—An easy, insensible slope.

GLASS-PLATE.—Specific gravity, 2·453; weight of a cubic foot, 153 lbs.; expansion by 180° of heat, from 32° to 212°, ·00086 inch.

GLAZING, as is now practised, embraces the cutting of all kinds of glass manufactured for windows, together with the fixing of it in sashes by means of brads and putty; also the formation of casements, and seaming the glass by bands of lead fastened to outside frames of iron.

GLUING-UP COLUMNS, p. 184.

GLYPHS. In sculpture and architecture, a notch, channel, or cavity, intended as an ornament. Used in combination chiefly, as *tryglyph* (which see).

GOBBETS.—Blocks of stone; squared blocks of stone.

GODROON, Gadroon.—An ornament, consisting of beadings or cablings.

GORE.—A wedge shaped or triangular piece.

GOING of a Step, and Going of the Flight, p. 196.

GOTHIC.—In architecture, a term at first applied opprobriously to the architecture of the middle ages, but now in general use as its distinctive appellation. By some the term Gothic is considered to include the Romanesque, Saxon, and Norman styles, which have circular arches, but it is strictly applicable only to the styles which are distinguished by the pointed arch. Gothic architecture so restricted has been divided into three distinct styles or periods, which have been variously named by different authors, but the terms most generally used are those bestowed by Mr. Rickman. By him the first period is named the Early English, it prevailed in the thirteenth century; the second, the Decorated, prevailed in the fourteenth century; and the third, the Perpendicular style, commenced in the end of the fourteenth, and continued in use till the middle of the sixteenth century. The chief characteristics of Gothic architecture are:—The predominance of the arch and the subserviency and subordination of all the other parts to this chief feature; the tendency of the whole composition to vertical lines; the absence of the column and entablature of classic architecture, of square edges

and rectangular surfaces, and the substitution of clustered shafts, contrasted surfaces, and members multiplied in rich variety.

GOTHIC ARCHES.–Construction of, p. 28-30.

GOTHIC GROINS, to draw the arches of, to mitre truly with a given arch of any form, p. 30.

GOTHIC MOULDINGS.—Characteristics of the various periods or styles of, p. 180.

GOTHIC MOULDINGS.—Illustrations of, Plate LXV.a p. 180.

GOTHIC VAULT.—Manner of dividing it into compartments, p. 82.

GOTTENBURG TIMBER. See PINUS SYLVESTRIS, p. 116, 117.

GRADE.—A step or degree.

GRADE, *v.*—To reduce to a certain degree of ascent or descent, as a road or way.

GRADIENT.—The degree of slope or inclination of a road.

GRAINING.—Painting in imitation of the grain of wood.

GRASS TABLE.—In Gothic buildings, the first horizontal or slightly inclined surface above the ground; the top of the plinth.

GRATING.—A framework of timber, composed of beams crossing each other at right angles, used to sustain the foundations of heavy buildings in loose soils. See GRILLAGE.

GRECIAN ARCHITECTURE.—This term is used to distinguish the architecture which flourished in Greece from about 500 years before the Christian era, or perhaps a little earlier, until the Roman conquest. It comprehends the Doric, Ionic, and Corinthian orders, to which may probably be added the Caryatic order. Of these the Doric is the most distinctive, and may be regarded as the national style. The architecture of the Greeks is known to us only through the remains of their sacred edifices and monuments, and we have no means of ascertaining in what manner it was applied to their houses. Simple and grand in their general composition, perfect in proportion, enriched, yet not encumbered with ornament of consummate beauty, these remains cannot be surpassed in harmony of proportion and beauty of detail.

GREEN-HEART TIMBER.—Description of, and properties and uses of, p. 112.

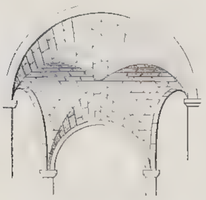
GREES, GRESE, GRYSE.—This word, which is variously spelled, signifies a step or degree.

GREY-STOCK BRICKS.—The hardest of the malm bricks. They are of a pale brown colour.

GRILLAGE.—A framework composed of beams laid longitudinally, and crossed by similar beams notched upon them, used to sustain walls, and prevent their irregular settling in soils of unequal compressibility. The grillage is firmly bedded and the earth packed in the interstices between the beams, a flooring of thick planks, termed a *platform*, is then laid, and on this the foundation courses of the wall rest.

GROIN.—The line made by the intersection of simple vaults crossing each other at any angle. See p. 76.

GROINED ARCH.—An arch formed by the intersection of two semicylinders or arches.



Groined Arch.

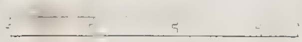
GROINED ROOF, OR CEILING.—A ceiling formed by three or more intersecting vaults, every two of which form a groin at the intersection, and all the groins meet in a common point, called the *apex* or *summit*. The curved surface between two adjacent groins is termed the *sectroid*. Groined roofs are common to classic and mediæval architecture, but it is in the latter style that they are seen in their greatest perfection. In this style, by increasing the number of intersecting vaults, varying their plans, and covering their surface with ribs and veins, great variety and richness were obtained, and at length the utmost limit of complexity was reached in the fan groin tracery vaulting. See FAN TRACERY.

GROINS in rectangular vaults, p. 77, 78.

GROINS on a circular plan, p. 79.

GROINS on an octagonal plan, p. 79, 80.

GROOVING AND TONGUING, GROOVING AND FEATHERING, PLOUGHING AND TONGUING.—In joinery, a mode of joining boards, which consists in forming a groove or channel along the edge of



Grooving and Tonguing

one board, and a continuous projection or tongue on the edge of another board. When a series of boards is to be joined, each board has a groove on its one edge and a tongue on the other. See p. 182.

GROTESQUE.—1. Applied to artificial grotto-work, decorated with rock-work, shells, &c.—2. That style of ornament which, as a whole, has no type in nature; the parts of animals, plants, and other incongruous elements being combined together.

GROUND-FLOOR.—Properly, that floor of a house which is at the base, but usually that which is on a level with or a little above the ground without.

GROUND-JOISTS.—Joists which rest on dwarf-walls, prop-stones, or bricks laid on the ground; sleepers.

GROUND-LINE.—In perspective, the intersection of the plane of the picture with the ground-plane. See p. 228.

GROUND-MOULD.—An invert mould, used in tunnelling operations, or any mould by which the surface of ground is formed.

GROUND-PLAN.—The plan of that story of a house which is on the level of the surface of the ground, or a little above it.

GROUND-PLANE.—In perspective, the plane on which the objects to be represented are supposed to be situated. See p. 228.

GROUND-PLATE, OR GROUND-SILL.—The lowest horizontal timber into which the principal and other timbers of a wooden erection are inserted.

GROUND-TABLE STONES.—The top of the plinth of a Gothic building. See EARTH-TABLE, GRASS-TABLE.

GROUNDS.—In joinery, pieces of wood attached to a wall for nailing the finishings to. They have their outer surface flush with the plastering. See p. 185.

GROUPED COLUMNS, OR PILASTERS.—A term used to denote three, four, or more columns or pilasters assembled on the same pedestal. When two only are placed together, they are said to be *coupled*.

GROUT.—Mortar in a fluid state, used to fill in the joints in brick-work, or the cavities in rubble building.

GUILLOCHE.—An interlaced ornament, formed by two or more intertwining bands, frequently used in classical architecture to enrich the torus and other mouldings.

Guttæ

GUTTÆ.—Ornaments resembling drops, used in the Doric entablature, immediately under the triglyph and mutule.

H.

HACKING.—In walling, a manner of building in which a course of stones, begun with single stones in height, is interrupted and carried on in two stones in height, but so as to make the two courses at the one end equal in height to the one course at the other.

HACKING-OUT TOOL.—A knife for removing old putty out of the rebates of a sash, preparatory to inserting a new pane of glass.

HACKMATACK.—The popular name of the red larch, *Pinus microcarpa*, but more commonly applied to the *Pinus pendula*.

HACKS.—The rows in which bricks are laid to dry after they are moulded

HAFFIT.—The fixed part of a lid or cover, to which the moveable part is hinged.

HALF-HEADER.—In bricklaying, a brick either cut longitudinally into two equal parts, or cut into four parts by these halves being cut across transversely, used to close the work at the end of a course.

HALF-LONG (Scotch, *Halflin*).—One of the bench-planes.

HALF-ROUND.—A moulding whose profile is a semicircle; a bead; a torus.

HALF-SPACE, OR FOOT-PACE.—The resting place of a staircase; the broad space or interval between two flights of steps. When it occurs at the angle turns of a stair, it is called a *quarter-space*. See p. 196.

HALF-TIMBERED HOUSES. See description and illustration, p. 156, Plates XLVI. and XLVII.

HALVING.—A mode of joining two timbers by letting them into each other. See p. 149.

HAMMER-BEAM.—A short beam attached to the foot of a principal rafter in a roof, in the place of the tie beam. Hammer-beams are used in pairs, and project from the wall, but do not extend half way across the apartments. The hammer-beam is generally supported by a rib rising up from a corbel below; and in its turn forms the support

Hammer beam Roof, Westminster Hall.

of another rib, constituting with that springing from the opposite hammer-beam an arch. Although occupying the place of a tie in the roofing, it does not act as a tie; it is essentially a lever, as will be obvious on an examination of the figure. Here the inner end of the hammer-beam A receives the weight of the upper portion of the roof, which is balanced by the pressure of the principal at its outer end. See also p. 145, description of the roof of Westminster Hall, and illustration, Plate XXXII.

HANCE.—A term in mediæval architecture, and that which immediately succeeded it, which seems to have been limited in its application to the small arches, at the springing of three and four centred arches, and to the small arches by which a straight lintel is sometimes united to its jamb or impost.

HANDRAIL.—A rail to hold by. It is used in staircases to assist in ascending and descending. When it is next to the open newel, it forms a coping to the stair balusters.

HANDRAILING.—Definition of terms, p. 201.

HANDRAILING, Elucidation of the principles of.—Section of a cylinder, p. 202.

HANDRAILING.—To produce the section of a cylinder, through any three points on its convex surface, p. 202.

HANDRAILING.—Summary of the leading points of difference between the method of Mr. Nicholson and that here taught, p. 203.

HANDRAILING.—Method of producing the face-mould and falling-mould for the stairs, Fig. 1, Plate XCI. p. 204.

HANDRAILING.—Method of producing the falling and face moulds for the stairs, Fig. 2, Plate XCI. p. 205.

HANDRAILING.—Method of producing the falling and face moulds for, Fig. 1, Plate XC. p. 205.

HANDRAILING.—Method of producing the face and falling moulds for scrolls, p. 205, 206.

HANDRAILING.—Sections of handrails, how to draw, p. 207.

HANDRAILING.—Mitre cap, how to form the section of the, p. 207.

HANDRAILING.—To form the swan-neck at the top of a rail, p. 207.

HANDRAILING.—To form the knee at the bottom newel, p. 207.

HANDRAILING.—Scrolls, how to draw, p. 207.

HANDRAILING.—The scroll step, how to form, p. 208.

HANDRAILING.—Vertical scrolls, how to draw, p. 208.

HANGING BUTTRESS.—A buttress not rising from the ground, but supported on a corbel. Applied chiefly as a decoration, and used only in the Decorated and Perpendicular styles.

Hanging Buttress.

HANGING STYLE OF A DOOR OR GATE.—That to which the hinges are fixed.

HANGINGS.—Linings for rooms, consisting of tapestry, leather, paper, and the like. They were originally invented to hide the rudeness of the carpentry or the harsh appearance of the bare wall. Paper-hangings were introduced early in the seventeenth century.

HATCHET.—A small axe with a short handle, used with one hand for reducing the edges of boards, &c.

HAUNCH OF AN ARCH.—The middle part between the vertex or crown and the springing.

HAUNCHING, p. 182.

HAWK.—A small quadrangular board, with a handle underneath, used by plasterers to hold their plaster.

HAWK-BOY.—A boy who attends on a plasterer, and supplies his *hawk* with stuff.

HAWTHORN, The.—Properties and uses of, p. 115.

HEAD-PIECE.—The capping-piece of a quartered partition, or of any series of upright timbers.

HEAD-POST.—The post in the stall partition of a stable which is nearest to the manger.

HEAD-WALL.—The wall in the same plane as the face of the arch which forms the exterior of a bridge.

HEADER.—1. In masonry, stones extending over the thickness of the wall; through stones.—2. In brick-work, bricks which are laid lengthways across the thickness of the wall.

HEADING-COURSE.—A course of stones or bricks laid lengthways across the thickness of a wall.

HEADING-JOINT.—The joint of two or more boards at right angles to their fibres.

HEART BOND.—In masonry, a kind of bond in which two stones forming the breadth of a wall have one stone of the whole breadth placed over them.

HEART-WOOD.—The central part of the trunk of a tree; the *duramen*. See description of Exogens, p. 94-96.

HELICAL LINE OF A HANDRAIL.—The spiral line twisting round the cylinder, representing the squared handrail before it is moulded.

HELICES. Projection of, p. 67.

HELIX.—A scroll or volute; in the plural, *helices*. The small volute or caulicule under the abacus of the Corinthian capital. In every perfect capital there are sixteen helices, two at each angle and two meeting under the middle of each face of the abacus.

HEMICYCLE.—A semicircle. See description of the hemicycles of M. Philibert de Lorme, p. 144.

HEMISPHERE, A.—To find the shadow on the concave surface of, p. 220.

HENDECAGON, OR ENDECAGON.—A figure of eleven sides and eleven angles. To find its area. Multiply the square of the side by 9·3656411.

HEPTAGON.—A figure having seven sides and angles. To find its area. Multiply the square of its side by [illegible]

HERNOSAND TIMBER. See PINUS SYLVESTRIS, p. 116, 117.

HERRING-BONE WORK.—Courses of stone

[illegible]

[illegible] angularly, so that the inclined courses are placed obliquely to the right and left alternately. It receives its name from the resemblance which the courses have to the bones of herring. See Plate XLIV., French Floors, Fig. 1, for illustration of Flooring boards laid herring bone fashion.

HEXÆDRON. A cube.

HEXÆDRON. One of the five regular solids. It is bounded by six squares. To find the surface. Multiply the square of its linear side by 6·0000000. To find the solid content. Multiply the cube of its linear side by 1·000000.

HEXAGON.—A figure of six sides and six angles. To find its area. Multiply the square of the side by 2·5980762.

HEXAGON.—To reduce a hexagon to a pentagon, Prob. XXII. p. 9.

HEXAGON.—Upon a given straight line, to describe a regular hexagon, Prob. XXXIX. p. 12.

HEXAGONAL PYRAMID, A. To find the shadow of, p. 221.

HEXASTYLE, HEXASTYLOS.—A building with six columns in front.

HICKORY WOOD (*Juglans alba*), p. 111.

HILING, HELING.—The covering of the roof of a building; slating; tiling.

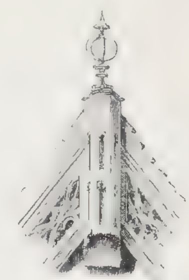
HINGED OR FRENCH SASHES, p. 187.

HINGES.—The hook or joint on which a door or gate turns. Hinges are the joints on which doors, lids, gates, shutters, and an infinite number of articles, are made to swing, fold, open, or shut up. They are made in a great variety of forms, to adapt them to particular purposes. See p. 191.

HINGING. Various modes of, described, p. 191.

HIP.—A piece of timber placed in the line of meeting of the two inclined sides of a hipped roof, to receive the jack rafters. It is also called a *hip-rafter*, and in Scotland a *piend rafter*.

HIP-KNOB.—A finial or other similar ornament placed on the top of the hip of a roof, or on



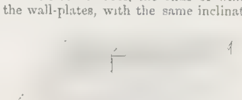
Hip-knob, Coventry

the point of a gable. When used upon timber gables, or on gables with barge-boards, the hip-knob generally terminates with a pendant.

HIP-MOULDING, OR HIP-MOULD.—Any moulding on the hip-rafter. More commonly used to denote the backing of a hip-rafter.

HIP-RAFTER.—The rafter which forms the hip of a roof; a piend-rafter. See p. 91.

HIP-ROOF.—A roof, the ends of which rise from the wall-plates, with the same inclination as



Hip-roof

the other two sides. Called in Scotland a *piend-roof*. See p. 91.

HIP-ROOFS.—Preliminary notions, p. 91.

HIP-ROOFS.—Construction of, for regular and irregular plans, and methods of finding the lengths of the rafters, the backing of the hips, and the bevels of the shoulders of the jack-rafters and the purlins, p. 91, 92.

HOARDING. A timber inclosure round a building, to store materials when the building is in course of erection or undergoing repair.

HOD.—A kind of tray used in bricklaying, for carrying mortar and bricks. It is fitted with a handle, and borne on the shoulder. A hod for mortar is 9 inches by 9 inches, and 14 inches long. It contains 1134 cubic inches, or 8 duodecimal inches; and two hods of mortar are equal to a bushel nearly. Four hods of mortar will lay 100 bricks. A hod contains 20 bricks.

HOGGING.—The drooping of the extremities and consequent convex appearance of any timber supported in the middle.

HOLDFAST.—A hook or long nail, with a flat short head, for securing objects to a wall; a bench-hook.

HOLING.—Piercing the holes for the rails of a stair.

HOLLOW.—A concave moulding. Sometimes called a *casement*.

HOLLOW NEWEL.—In architecture, an opening in the middle of a staircase. It is used in contradistinction to a solid newel, which has the end of the steps built into it. In the hollow newel the ends of the steps next the hollow are unsupported, the other ends being only supported by the surrounding wall of the staircase.

HOLLOW QUOINS.—The part of the piers of a lock-gate, in which the heel post or hanging-post of the gate turns.

HOLLOW WALL.—A wall built in two thicknesses, with a cavity between, either for the purpose of saving materials or of preserving a uniformity of temperature in the apartments.

HOOD-MOULDING, HOOD-MOULD.—The upper and projecting moulding over a Gothic door or window, &c.; called also a *label*, *drip*, or *weather-moulding*. See woodcut, DRIPSTONE.

HORIZONTAL LINE. In perspective, the line of intersection of the horizontal plane with the plane of the picture. See p. 229.

HORIZONTAL PLANE.—In perspective, a plane parallel to the horizon, passing through the eye and cutting the plane of the picture at right angles. See p. 228.

HORNBEAM.—For description of properties and uses, see p. 113.

HORSE-CHESTNUT.—For description of properties and uses, see p. 114.

HOUSE, *v.*—To excavate a space in one timber for the insertion of another. See p. 196.

HOUSING.—1. The space taken out of one solid to admit of the insertion of the extremity of another, for the purpose of connecting them. See p. 196.—2. A niche for a statue.

HOVELLING.—A mode of preventing chimneys from smoking, by carrying up the two sides which are liable to receive strong currents, to a greater height than the others, or by leaving apertures in the sides, so that when the wind blows over the top the smoke may escape below.

HYPÆTHRAL.—A building or temple uncovered by a roof, as the famous temple of Neptune at Pæstum.

HYPERBOLA.—Construction of, p. 27, 28.

HYPERBOLA.—Description of the, p. 27.

HYPERBOLA.—To find the focus of a hyperbola, p. 28.

HYPERBOLA.—Mode of describing graphically, p. 28.

HYPERBOLA.—To draw, by means of a rule and a string, p. 28.

HYPERBOLA.—To draw tangents and perpendiculars to the curve of a hyperbola, p. 28.

HYPERBOLA.—To find points in the curve of a hyperbola, the axis, vertex, and ordinate being given, p. 28.

HYPOTRACHELIUM.—The neck of the capital of a column; the part which forms the junction of the shaft with its capital. See NECK.

I.

ICHNOGRAPHY.—In architecture and perspective, the horizontal section of a building or other object; a plan.

ICOSAHEDRAL.—Having twenty equal sides.

ICOSAHEDRON.—The projections of an, to construct, p. 56, 57.

ICOSAHEDRON.—A solid of twenty equal sides. The regular icosahedron is a solid, consisting of twenty triangular pyramids, whose vertices meet in the centre of a sphere supposed to circumscribe it; and therefore they have their bases and heights equal.—To find the surface of an icosahedron. Multiply the square of its linear side by 8·6602540.—To find the solidity of an icosahedron. Multiply the cube of its linear side by 2·1816950.

IMPAGES.—A term used by Vitruvius, and supposed to signify the rails of a door.

IMPERIAL.—A roof or dome in the form of an imperial crown.

IMPERIALS.—In slating, slates measuring 2 feet 6 inches by 2 feet.

IMPOST.—The congeries of mouldings forming a cap or cornice to a pier, abutment, or pilaster, from which an arch springs.

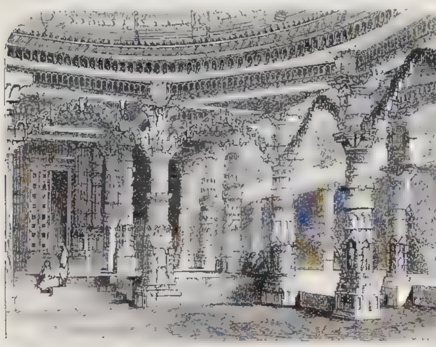
b. Impost

INCERTUM.—A mode of building used by the Romans, in which the stones were not squared nor the joints placed regularly. It corresponds to the modern *rubble-work*.

INCISE.—To cut in; to carve.

INDENTED.—Cut in the edge or margin into points like teeth, as an indented moulding. Indented mouldings are much used in the transition from the Norman to the Early English style, and sometimes in the Early English style itself.

INDIAN ARCHITECTURE.—The architecture of Hindoostan, in its details, bears a striking resemblance to the architecture of Persia and Egypt, and they are considered to have a common origin. Its monuments may be divided into two classes, the *excavated*, which is either in the form of a cavern, or in which a solid rock is sculptured into the resemblance of a complete building; and the *constructed*, in which it is actually a building, or formed by the aggregation of different materials. The first class is exemplified in the caves of Elephanta and Ellora, and the sculptured temples



Jain Temple, Mount Aboo, Gujerat.—Fergusson's Hindoo Architecture.

of Mavalipooram, and the second class in the pagodas of Chillimbaram, Tanjore, and others. The architecture of India resembles, in its details, that of Egypt, but its differences are also very striking. In the architecture of Egypt massiveness and solidity are carried to the extreme; in Indian architecture these have no place. In the former the ornaments are subordinate to the leading forms, and enrich without hiding them. In the latter the principal forms are overwhelmed and decomposed by the accessories. In the one grandeur of effect is the result, while littleness is the characteristic of the other. Besides the various styles of Hindoo architecture, properly so called, there is in Hindoostan a distinct series of buildings belonging to the Mahometan conquerors of that country, and consisting of palaces, mosques, and tombs. These partake strongly of the characteristic features of Saracenic architecture.

INJURY TO TIMBER, from being exposed to sudden or rapid changes of temperature, p. 100.

INNER PLATE.—The innermost of the two wall-plates in a double wall-plated roof.

INSERTED COLUMN.—The same as *engaged column* (which see).

INSERTUM. See INCERTUM.

INSULATED COLUMNS.—Those which stand clear from the walls, as opposed to attached or engaged columns.

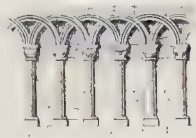
INTAGLIO.—Literally, a cutting or engraving; hence, anything engraved, or a precious stone with arms or an inscription engraved on it, such as we see in rings, seals, &c.

INTERCOLUMNIATION.—The space between two columns. This, in the practice of the ancients, varied almost in every building. Vitruvius enumerates five varieties of intercolumniation, and assigns to them definite proportions, expressed in measures of the inferior diameter of the column. These are—The pycnostyle, of one diameter and a half; the systyle, of two diameters; the diastyle, of three diameters; the areostyle, of four diameters; and the eustyle, of two and a quarter diameters. It is found, however, on examining the remains of ancient architecture, that they rarely or never agree with Vitruvian dimensions, which must therefore be regarded as arbitrary; and indeed the words themselves, as will be found on referring to them, convey no idea of an exactly defined space, but are in their very vagueness more applicable to the remains of ancient art.

INTERDUCE.—An intertie. See that term.

INTERJOIST.—The space between two joists.

INTERLACING ARCHES.—Circular arches which intersect each other, as in the figure. They



Interlacing Arcade, Norwich Cathedral

are frequent in arcades of the Norman style of the twelfth century, and in them Dr. Milner supposed the Pointed style to have had its origin.

INTERMODILLION.—The space betwixt two modillions.

INTERPILASTER.—The space between two pilasters.

INTERQUARTER.—The space between two quarters.

INTERTIE, INTERDUCE.—A short piece of timber introduced horizontally between uprights, to bind them together or to stiffen them. See p. 155, Partitions, and illustration, Plate XLV. Fig. 1, A A; Fig. 2, No. 2, D; Fig. 3, No. 1, C; and p. 156, Timber-houses, and illustration, Fig. 470, p. 157, O O O.

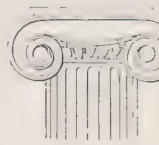
INTRADOS.—1. The interior or under concave curve of an arch. The exterior or convex curve is called the *extrados*. See woodcut, ARCH.—2. The concave surface of a vault. It is called also *douelle*.

INVERTED ARCH.—An arch with its intrados below the axis or springing line, and of which, therefore, the lowest stone is the keystone.

Inverted Arches

Inverted arches are used in foundations to connect particular points, and distribute their weight or pressure over a greater extent of surface, as in piers and the like.

IONIC ORDER.—The second of the three Grecian and third of the five Roman orders. The distinguishing characteristic of this order is the voluted capital of the column. In the Grecian Ionic capital the volutes appear the same on the rear as on the front, and are connected on the flanks by a peculiar roll-moulding, called the *baluster* or *bolster*. In the exterior columns of a portico, however, the volutes are repeated on the outer flank, and are thus necessarily angular. The Grecian Ionic may be considered in three parts—the stylobate, column, and entablature. The stylobate is from four-fifths to a whole diameter in height, and is in three receding steps. The column is rather more than nine diameters in height. Of this two-fifths of a diameter are given to the base, and from three-fourths to seven-eighths to the capital, including the hypotrachelium. The base is divided into three nearly equal parts in height, with two equal fillets separating them. The lowest is a torus, which rests on



Grecian Ionic Capital

the stylobate; this is separated from a scotia above by a fillet, and another fillet intervenes between the scotia and another torus, and from a third fillet the scape or apophyge of the shaft springs. The shaft diminishes in a curved line to its upper diameter, which is five-sixths of its lower diameter, or sometimes more. It is fluted with twenty-four flutes, with fillets one-fourth of their width between. The hypotrachelium or necking of the capital is sometimes separated from the shaft by a plain fillet, and sometimes by a carved bead, and is generally ornamented. Above this the mouldings of the capital spring out. They consist generally of a bead, an ovolo, and a torus, all richly carved, and on these rest the square mass, on the faces of which are the volutes, and on this rests the abacus, whose edges are moulded into the form of an ovolo, and sometimes ornamented with the egg-and-tongue. The entablature is rather more than two diameters in height. If this be divided into five parts, two of them may be given to the architrave, two to the frieze, and the remaining part to the cornice. If the architrave, again, be divided into nine parts, seven of them may be given to three equal fascias, and the remainder to the band of architrave mouldings. The frieze may be plain or enriched with sculpture in low-relief. The cornice consists of bed-mouldings, corona, and crowning mouldings. The bed-mouldings are composed of a bead and a cyma reversa, both carved. The cyma reversa is contained in the depth of the corona, whose bed is hollowed out for that purpose. The crown mouldings are rather more than one-fourth of the height of the cornice, and consist of a carved bead, an ovolo, also carved, and a crowning fillet. This is a general description of the composition of the Ionic order of the Erechtheium on the Acropolis at Athens, the most perfect example left to us, produced probably about 420 years B.C., the great epoch of Athenian art.—The Roman Ionic. This order in the hands of the Romans suffered great debasement. The angular volute of the Greeks was a clumsy enough expedient to get rid of a difficulty which need never have arisen if the order had been used either in antis or attached; but the Romans, not content with this, made in many cases volutes at all the four angles of the column, and then curved all the sides of the abacus. The Ionic, as used by the Italian architects, varied much in proportions; but the following are those given by Sir William Chambers, in diameters and minutes, or sixtieths of a diameter:—The column is nine diameters high, of which the base occupies thirty, and the capital twenty-one minutes. The architrave, divided into two fascias, is forty and a half minutes, the frieze also forty and a half minutes, and the cornice fifty-four minutes. The separation between the fascias of the architrave is made by a fillet and carved ovolo. The architrave mouldings consist of a carved ogee and a fillet. The frieze is plain. It is surmounted by an ogee serving as a bed-moulding to a dentil band equal in depth to rather more than a fifth of the cornice. Over this is an ovolo, serving as the bed-moulding of the corona; then the corona, in height equal to nearly a fifth of the cornice; and then the crowning mouldings, consisting of an ogee, a fillet, and a cyma recta. When a pedestal is used, the same authority makes it two diameters and six-tenths in height.

IRON.—To find the weight of.—1. Wrought iron close hammered: find the number of cubic inches contained in the mass, multiply this by 28, cut off two figures to the right hand, and the remainder is lbs. 2. Cast iron: proceed as above, but multiply by 26 instead of 28.

IRON TIE-RODS.—Dimensions of, for various spans. See TIE-ROD.

ISLE, ILE, a spelling formerly incorrectly used, instead of *aile* or *aisle* (which see).

ISODOMON, ISODOMUM.—In Grecian architecture, a species of walling in which the courses were of equal thickness and equal lengths.

INDEX AND GLOSSARY.

ISOMETRICAL PROJECTION, p. 242.

ITALIAN ARCHITECTURE.—Under this term are comprehended the three great architectural schools of Italy—the Florentine, the Roman, and the Venetian. The architecture of Florence is best displayed in its palaces. In the façades of these, columns are used only as ornamental accessories, and however many the horizontal divisions or stories, the reigning cornice is proportioned to the whole height of the building, considered as an order, and is in general boldly pronounced and richly decorated. This is the severest of the Italian schools, and the exteriors of these palaces have a solidity, monotony, and solemnity which would make them appear as fortified places, if it were not for their richly-ornamented cornices. In the Roman school the architecture is less massive; columns are introduced freely, and grandeur of effect without severity is studied. The Venetian school is characterized by lightness and elegance, and the free use of columns, pilasters, and arcades.

J.

JACK-ARCH. An arch of a brick in thickness.

JACK-PLANE.—One of the bench-planes. It is about eighteen inches long, and is used in reducing inequalities in the timber preparatory to the use of the trying plane.

JACK RAFTER. See JACK TIMBERS, and p. 91, voce HIP-ROOF.

JACK-RIB. See JACK TIMBERS.

JACK TIMBERS.—Those timbers in a series which, being intercepted by some other piece, are shorter than the rest. Thus, in a hipped roof, each rafter which is shorter than the side-rafters is a jack-rafter.

JAMB-LININGS. The linings of the vertical sides of a doorway.

JAMB-POSTS.—The upright timbers on each side of a doorway, called also *prick-posts*. See p. 17..

JAMB STONES.—Those employed in constructing the vertical sides of an opening.

JAMBS.—The vertical sides of any aperture, such as a door, a window, or chimney.

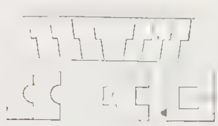
JERKIN-HEAD.—The end of a roof not hipped down to the level of the side walls, the gable being carried up higher than those walls. A truncated hipped roof.

JESTING-BEAM.—A beam introduced for the sake of appearance and not for use.

JETTY.—A projecting portion of a building.

JIB-DOOR.—A door with its surface in the plane of the wall in which it is set. Jib-doors are intended to be concealed, and therefore they have no architraves or finishings round them, and the plinth and dado are carried across them. See p. 187 and Plate LXXIII.

JOGGLES, OR JOGGLE-JOINTS.—In architecture, the joints of stones or other bodies, so constructed and fitted together, as to prevent them from sliding past each other by any force acting in a direction perpendicular to the pressure by which



a a a, Joggle joints. *a* The last Joggle

they are thus held together. In masonry, this term is applied to almost every sort of jointing in which one piece of stone is let or fitted into another, so as to prevent all sliding on the joints. In carpentry, the struts of a roof are said to be joggled into the truss posts and into the rafters.

JOINER.—Materials used by the, p. 182.

JOINERY.—The art or practice of dressing, framing, joining, and fixing wood-work, for the internal and external finishings of houses. See Definition, p. 182.

JOINT.—1. In architecture, the surface of separation between two bodies that are brought into contact, and held firmly together by means of cement, mortar, &c., or by a superincumbent weight. The nearer the surfaces of separation approach each other, the more perfect the joint, but in masonry the contact cannot be made very close on account of the coarseness of the cement.—2. In carpentry and joinery, the place where one board or member is connected with another. Joints receive various names, according to their forms and uses. Pieces of timber are framed and joined to one another most generally by *mortises* and *tenons*, of which there are several kinds, and by iron straps and bolts. When it is required to join two pieces of timber so as to make a beam of a given length, and equal in strength to one whole piece of the same dimensions and length, this is done by *scarfing*.—*A longitudinal joint*, one in which the common seam runs parallel with the fibres of both.—*Abutting* or *butt joint*, one in which the plane of the joint is at right angles to the fibres, and the fibres of both pieces in the same straight line.—*Square joint*, one in which the plane of the joint is at right angles to the fibres of one piece, and parallel to those of the other.—*Bevel-joint*, one in which the plane of the joint is parallel to the fibres of one piece, and oblique to those of the other. *Mitre joint*, one in which the plane of the joint makes oblique angles with both pieces.—*Dovetail joint*. See DOVETAIL, also MORTISE, TENON, and SCARFING, and p. 146, 182.

JOINTER.—The largest plane used in straightening the edges of boards to be jointed together. In bricklaying, a crooked piece of iron bent in two opposite directions, and used for drawing, by the aid of the jointing-rule, the horizontal and vertical joints of the work.

JOINTING-RULE.—A straight-edge used by bricklayers for guiding the jointer in drawing in the joints of brick-work.

JOINTS AND STRAPS, p. 146, 182.

JOISTS.—The pieces of timber to which the boards of a floor, or the laths of a ceiling are nailed, and which rest on the walls or on girders, and sometimes on both. They are laid horizontally, in parallel equidistant rows. They are of a rectangular form, and placed with their edges uppermost, as the lateral strength of a horizontal rectangular beam to resist a force acting upon it is proportional to the breadth of the transverse section multiplied into the square of the depth. Flooring with only one tier of joists is termed *single-flooring*, and when two tiers are used, it is termed *double flooring*.—*Trimming-joists*, two joists, into which each end of a small beam, called a *trimmer*, is framed. See TRIMMER.—*Binding-joists*, or *binders*, in a double floor, are those which form the principal support of the floor, and run from wall to wall. *Bridging-joists*, those which are bridged on to the binding-joists, and carry the floor: they are laid across the binding joists. *Ceiling-joists*, cross-pieces fixed to the binding joists underneath, to sustain the lath and plaster. See FLOORS, p. 150.

JUBÉ.—The rood-loft, or gallery into the choir.

JUFFERS.—Pieces of timber four or five inches square in section.

JUGLANS ALBA.—White walnut or hickory, p. 111.

JUGLANS NIGRA.—Black or brown walnut. See p. 111.

JUMP.—An abrupt rise from a level course.

JUMPER.—A name given by masons and miners to a long iron chisel used in boring shot-holes, for blasting large masses of stone, by which they may be split into smaller ones.

JUTTY.—A projection in a building. The same as *jetty*.

K.

KEEP.—The stronghold of an ancient castle.

KEEPING THE PERPENDICULAR.—Causing the vertical joints in brick work to recur in the same straight line in each alternate course.

KERB or KIRB PLATE. See CURB-PLATE.

KERF.—The channel or way made through wood by a saw.

KERNEL.—The same as *crenelle* (which see).

KEY.—A name given to all fixing wedges.

KEY-PILE.—The centre pile plank of one of the divisions of sheeting piles contained between two gauge piles of a cofferdam, or similar work. It is made of a wedge form, narrowest at the bottom, and when driven, keys or wedges the whole together.

KEYED DADO.—In architecture, a dado that is secured from warping, by having bars of wood grooved into it across the grain at the back.

KEYHOLE SAW.—A saw used for cutting out sharp curves, such as keyholes require, whence its name. It consists of a narrow blade, thickest on the cutting or serrated edge, its teeth having no twist or set, and a long handle perforated from end to end, into which the blade is thrust to a greater or lesser extent, according to the nature of the work to be performed. The handle is provided with a pad and screw for fastening the blade when it is adjusted. It is also called a *turning-saw*.

KEYING a mortise joint, p. 147.

KEYS.—In naked flooring, pieces of timber fixed in between the joists by mortise and tenon. When these are fastened with their ends projecting against the sides of the joists, they are called *strutting-pieces*.

KEYSTONE.—The highest central stone of an arch; that placed on the top or vertex, to bind the two sweeps together. In some cases the keystone projects from the face, and is moulded and enriched. In vaulted Gothic roofs, the keystones are usually ornamented with a boss or pendant. See first woodcut under ARCH.

KILLESSE, CULLIS, COULISSE.—A gutter, groove, or channel. The term is corruptly applied in some districts to a hipped roof; as a *killessed* or *cullidged* roof. A dormer-window, too, is sometimes called a *killessed* or *cullidged* window.

KING-PIECE.—Another and more appropriate name for *king-post*.

KING-POST.—The post which, in a truss, extends between the apex of two inclined pieces and the tie-beam, which unites their lower ends as in a king-post roof. See p. 148, and woodcut, ROOF.

KING-TABLE.—In mediæval architecture, conjectured to be the string course, with ball and flower ornaments, usual under parapets.

KIOSK. A Turkish word signifying an open pavilion or summer-house supported by pillars.

KIRB-PLATE. See CURB-PLATE.

KIRB-ROOF. See CURB ROOF.

KNEE.—1. A piece of timber somewhat in the form of the human knee when bent.—2. A part of the back of a hand-rail, which is of a convex form, the reverse of a *ramp*, which is concave.—*Knee-piece* or *knee-rafter*, an angular piece of timber used to strengthen the joining of two pieces of timber in a roof.

KNOCKER.—A kind of hammer fastened to a door, to be used in seeking for admittance. The knockers of mediæval buildings present many

Knocker, Village of Street, Somersetshire

beautiful specimens of forged iron-work. They are often highly decorated, and sometimes assume very quaint and fantastic forms.

KNOT, OR KNOB.—A bunch of leaves, flowers, or similar ornament, as the bosses at the ends of labels, the intersections of ribs, and the bunches of foliage in capitals.

KNOTS IN WOOD.—Some kinds render wood unfit for the carpenter; some kinds are not prejudicial. See p. 98.

KNOTTING.—A process to prevent the knots of wood from appearing, by laying on a size composed of red led, white lead, and oil, or a coat of gold size, as the preliminary process of painting.

KNOTTY AND CROSS GRAINED WOOD.—Unfit for ordinary carpentry works. See p. 98.

KNOWLEDGE OF WOODS.—Physiological notions, p. 93.

KNUCKLE.—A joint of a cylindrical form, with a pin as axis, such as that by which the straps of a hinge are held together. See p. 190, HINGING; and Plates LXXXIV.–LXXXVI.

KYANIZE, *v.*—To steep in a solution of corrosive sublimate, as timber, to preserve it from the dry-rot.

L.

LABEL.—A projecting moulding over a door, window, or other opening; called also *dripstone*, *weather-moulding*, and, when in the interior, *hood-moulding*.

LABOUR-SAVING MACHINES.—Sketch of the introduction of, p. 191.

LABOUR-SAVING MACHINES. — Sir Samuel Bentham's inventions in, p. 191.

LABOUR-SAVING MACHINES.—American circular saw bench, and Furness' planing machine, Plate LXXXVII. and p. 192; Furness' patent mortising and tenoning machines, Plate LXXXVII^a and p. 193.

LABYRINTH FRET.—A fret with many involved turnings.

LACUNARIA or LACUNARS. — Panels or coffers in a ceiling.

LADIES.—In slating, small slates measuring about 15 inches long and 8 inches wide.

LADY-CHAPEL.—A chapel dedicated to the Virgin Mary, frequently attached to large churches. It was variously placed, but generally to the eastward of the high altar. In churches of an earlier date than the thirteenth century, the lady-chapel is generally an additional building. The term is of modern application. See woodcut, CATHEDRAL.

LAGGINS, LAGGING.—The planking laid on the ribs of the centering of a tunnel or bridge, to carry the brick or stone work. See p. 171.

LAMINATED ARCHES.—Arches composed of thin plates of wood fastened together. See p. 141.

LANCET ARCH.—One whose head is shaped like the point of a lancet. See p. 29.

LANCET WINDOW. — A window with a lancet arch. This kind of window is characteristic of the Early English style of architecture. Lancet windows have no tracery, and were often double or triple, and sometimes five were placed together. Though separated on the outside, lancet windows which are placed together are in the interior combined into one design by a wide splaying of the openings, and thus form, to a certain extent, a compound window.

Lancet Window, Comberton

LANDING. — The first part of a floor at the end of a flight of steps. Also, a resting place between flights. See p. 196.

LANTERN.—1. A drum-shaped erection, on the top of a dome, or the roof of an apartment, to give light, and serve as a sort of crowning to the fabric. It may be either circular, square, elliptical, or polygonal (see LOUVRE). Also, the lower part of a tower placed at the junction of the cross in a cathedral or large church, having windows on all sides.—2. A square cage of carpentry placed over the ridge of a corridor or gallery, between two rows of shops, to illuminate them, as in many public arcades.

LAP, *v.*—To lap boards is to lay one partly over the other.

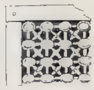
LAQUEAR.—The same as *lacunaria* or *lacunar*.

LARCH. Description and uses of, see p. 119.

LARMIER.—The corona or drip of a cornice; corruptly *lorimer*.

LATH.—1. A thin narrow board or slip of wood nailed to the rafters of a building, to support the tiles or covering.—2. A thin narrow slip of wood nailed to the studs, to support the plastering; also, a thin cleft piece of wood used in slating, tiling, and plastering. There are two sorts of laths, single and double; the former being barely a quarter of an inch, while the latter are three eighths of an inch thick. Pantile laths are long square pieces of fir, on which the pantiles hang.—*Lath floated and set fair*, three-coat plasterer's work, in which the first is called pricking up, the second floating, the third or finishing is done with fine stuff.—*Lath laid and set*, two-coated plasterer's work; except that the first is called *laying*, and is executed without scratching, unless with a broom.—*Lath plastered, set, and coloured*, the same as lath laid, set, and coloured.—*Lath pricked up, floated, and set for paper;* the same as lath floated and set fair.

LATTICE.—Any work of wood or iron, made by crossing laths, rods, or bars, and forming open chequered or reticulated work. — *Lattice*, or *lattice window*, a window made of laths or strips of iron which cross one another like net-work, so as to leave open interstices. It is only used when air rather than light is to be admitted. Such windows are common in hot countries, and in these the lattice work is frequently arranged in handsome devices.



Lattice Work, Cairo

LATTICE BRIDGE, p. 169.

LAYER BOARDS. The boards for sustaining the lead of gutters.

LEAD, in excavator's work, is the distance to which the materials have to be removed.

LEAD NAILS.—Nails used to fasten lead, leather, canvas, &c., to wood. They are of the same form as clout nails, but are covered with lead or solder.

LEAF.—The side of a double door.

LEAF BRIDGE.—A bridge consisting of two opening leaves.

LEAN TO.—A building whose rafters pitch against or lean on to another building, or against a wall.

LEAR BOARD. — The same as *layer board*.

LECTERN or LETTERN.—The reading desk in the choir of ancient churches and chapels. It was generally of brass, and sometimes elaborately carved. Its use has been almost entirely superseded in England by the modern reading desk, or rather reading pew.

LEDGE.—A surface projecting horizontally, or slightly inclined to the horizon; a string course; also, the side of a rebate, against which a door or shutter is stopped, or a projecting fillet serving the same purpose as a door stop, or the fillet which confines a window frame in its place.

LEDGED DOORS.—Doors formed of deals, with cross pieces on the back to strengthen them. See p. 186.

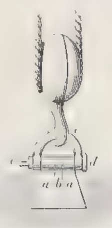
LEDGERS.—The horizontal timbers used in scaffolding.

LEDGMENT.—1. A laying out; the development of the surface of any solid on a plane, so that its dimensions may be readily obtained.—2. The same as *ledge;* a string course or horizontal moulding.

LEDGMENT TABLE.—In mediæval architecture, a name given to any of the tables of the base, except the ground table.

LENGTHENING BEAMS.—By scarfing and by fishing, p. 148.

LEWIS, LEWISSON (Fr. *louve, louveceau*).—An instrument of iron, used in raising large stones to the upper part of a building, which operates by the dovetailing of one of its ends into an opening in the stone. It consists of two moveable parts *a a*, perforated at their heads to admit the pin or bolt *c d*. These are inserted, by hand, into the cavity formed in the stone; and between them the part *b* is introduced, which pushes their points out to the sides of the stone, thus filling the cavity; *e* a half-ring bolt, with a perforation at each end; to this the tackle above is attached by a hook. The fastening-pin passes horizontally through all the holes, entering at the right side *d*, and forelocking on the other end *c*.



Lewis.

LICH-GATE — A shed over the gate of a churchyard to rest the corpse under; called also a *corpse-gate*.

LIME TREE, LINDEN TREE. — Description and uses of, p. 113.

LINE OF LINES ON THE SECTOR, p. 37.

LINE OF CHORDS ON THE SECTOR.—Construction and use of, p. 37.

LINE OF POLYGONS ON THE SECTOR. — Construction and use of, p. 38.

LINE OF PROJECTION.—In perspective, the intersection of the plane of the picture with the ground plane.

LINE OF NOSINGS, p. 196.

LINE OF SECANTS ON THE SECTOR.—Construction and use of, p. 39.

LINE OF SINES ON THE SECTOR.—Construction and use of, p. 39.

LINE OF TANGENTS ON THE SECTOR.—Construction and use of, p. 39.

LINEAL MEASURES. See WEIGHTS AND MEASURES.

LINEAR PERSPECTIVE.—That branch of perspective which regards only the positions, magnitudes, and forms of the objects delineated.

LINING.—In architecture, the covering of the surface of any body with a thinner substance. The term is only applied to coverings in the interior of a building, coverings on the exterior being properly termed *casings*. Lining of boxings for window shutters, are the pieces of framework into which the shutters are folded back. Linings of a door are the coverings of the jambs and soffit of the aperture.—*Lining out stuff*, drawing lines on a piece of board or plank, so as to cut it into thinner pieces.

LINTEL.—A horizontal piece of timber, iron, or stone placed over an opening. See p. 156.

LIST, LISTEL.—A fillet moulding.

LOBBY.—1. A small hall or waiting-room; also, an inclosed space surrounding or communicating with one or more apartments; such as the boxes of a theatre. When the entrance to a principal apartment is through another apartment, the dimensions of which, especially in width, do not entitle it to be called a vestibule or antechamber, it is called a lobby.—2. A small apartment taken from a hall or entry.

LOCK.—1. Lock, in its primary sense, is anything that fastens; but in the art of construction the word is appropriated to an instrument composed of springs, wards, and bolts of iron or steel, used to fasten doors, drawers, chests, &c. Locks on outer doors are called *stock locks;* those on chamber doors, *spring locks;* and such as are hidden in the thickness of the doors to which they are applied, are called *mortise locks.*—2. A basin or chamber in a canal, or at the entrance to a dock. It has gates at each end, which may be opened or shut at pleasure. By means of such locks vessels are transferred from a higher to a lower level, or from a lower to a higher. Whenever a canal changes its level on account of an ascent or descent of the ground through which it passes, the place where the change takes place is commanded by a lock.

LOCK-CHAMBER.—In canals, the area of a lock inclosed by the side walls and gates.

LOCK-GATE. The gate of a lock provided with paddles, &c. See DOCK-GATES, p. 177, and Plates LXI. and LXII.

LOCK-PADDLE. The sluice in a lock which serves to fill or empty it.

LOCK-PIT.—The excavated area of a lock.

LOCK-RAIL.—The middle rail of a door, to which the lock or fastening is fixed. See p. 186.

LOCK-SILL —An angular piece of timber at the bottom of a lock, against which the gates shut.

LOCK-WEAR.—A paddle-wear, in canals, an over-fall behind the upper gates, by which the waste water of the upper pond is let down through the paddle-holes into the chamber of the lock.

LOCKER.—1. A small cupboard.—2. A small closet or recess, frequently observed near an altar in Catholic churches, and intended as a depository for the sacred vessels, water, oil, &c.

LOCUTORY.—An apartment in a monastery, in which the monks were allowed to converse when silence was enjoined elsewhere.

LODGE.—1. A small house in a park, forest, or domain, subordinate to the mansion; a temporary habitation; a hut.—2. A small house or cottage appended to a mansion, and situated at the gate of the avenue leading to the mansion; as a porter's *lodge*.

LOFT.—In modern usage this term is restricted to the place immediately under the roof of a building, when not used as an abode; as *hay-loft*. The gallery of a church is sometimes termed the *loft* in Scotland.

LOGARITHMIC LINES ON THE SECTOR.—Construction and use of, p. 40.

LOMBARD ARCHITECTURE. — A name given to the round-arched Gothic of Italy, introduced by the conquering Goths and Ostrogoths, which superseded the Romanesque, and reigned from the eighth to the twelfth century. "At first," says Mr. Fergusson, "when the barbarians were few, and the Roman influence still strong, they of course were forced to adopt the style of their predecessors, and to employ Italian builders to execute for them works they themselves were incapable of producing; but as they became stronger they threw off the trammels of an art with which they had no sympathy, to adopt one which expressed their own feelings; and although the old influence still lay beneath, and occasionally even came to the surface, the art was Gothic in all essentials, and remained so during nearly the whole of the middle ages.

LONG PLANE, or JOINTER. See JOINTER.

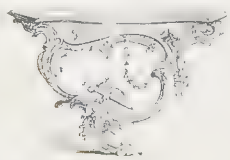
LOOP-HOLE.—A narrow opening in a wall.

LOUIS-QUATORZE, STYLE OF.—A meretricious style of ornament and ornamental decoration developed in France during the reign of Louis XIV. The great medium of this style was gilt stucco-work, and its most striking characteristics are an infinite play of light and shade, and a certain disregard of symmetry of parts, and of symmetrical

Louis-Quatorze Ornament

arrangement. The characteristic details are the scroll and shell. The classical ornaments, and all the elements of the Cinque-cento, from which the Louis-Quatorze or Louis XIV. proceeded, are admitted, under peculiar treatment, or as accessories; the panels are formed by chains of scrolls, the concave and convex alternately; some clothed with an acanthus foliation, others plain.

LOUIS-QUINZE, STYLE OF.—A variety of the Louis Quatorze style of ornament, which prevailed in France during the reign of Louis XV., in which the want of symmetry in the details, and of



Louis-Quinze Ornament

symmetrical arrangement, which characterize the Louis XIV. style, are carried to an extreme. An utter disregard of symmetry, a want of attention to masses, and an elongated treatment of the foliations of the scroll, together with a species of crimped conventional shell-work, are characteristics of this style.

LOUVRE, LOOVER, LOVER, OR LANTERN.—A dome or turret rising out of the roof of the hall in our ancient domestic edifices; formerly open at the sides, but now generally glazed. They were originally intended to allow the smoke to escape,

Louvre, Abbot's Kitchen, Glastonbury

when the fire was kindled on dogs in the middle of the room. The open windows in church-towers are called *louvre-windows*, and the boards or bars which are placed across them to exclude the rain, are called *louvre-boards*, corruptly *luffer-boards*.

LOZENGE MOULDING, OR LOZENGE FRET.—An ornament used in Norman architecture, presenting the appearance of diagonal ribs inclosing diamond shaped panels.

LUFFER-BOARDING. See LOUVRE.

LUMBER.—In America, timber sawed or split for use.

LUNETTE. An aperture in a concave ceiling for the admission of light.

LYING PANELS. –Those in which the fibres of the wood lie in a horizontal direction.

LYSIS.—A plinth or step above the cornice of the podium which surrounds the stylobate.

M.

M ROOF.—A kind of roof formed by the junction of two common roofs, with a valley between them.

MACHICOLATIONS.—In castellated architecture, openings made through the roofs of portals to the floor above, but more generally openings made in the floor of projecting galleries for the purpose of defence, by pouring through them boiling pitch, molten lead, &c., upon the besiegers. In the latter case they are formed by the parapet or breast-work B being set out on corbels D, beyond the face of the wall C. The spaces E between the corbels, which are open throughout, are the machicolations. From its striking appearance, the corbelled gallery with its parapet, was frequently used when machicolations were not required for the purposes of defence, and the so-called apertures were

Machicolations, Herstmonceux Castle

omitted. Machicolations do not appear to have been used earlier than the twelfth century.

MACHINES WITH REVOLVING CUTTERS.—General remarks on, p. 194.

MAHOGANY. p. 115.

MAHOGANY TREE.—Description and uses of, p. 115.

MAIN BRACES. p. 159.

MAIN COUPLE.—A name given to the trussed principal of a roof.

MALM BRICKS.—Those composed of clay, sand, and comminuted chalk. They burn to a pale brown colour, more or less inclined to yellow, which is an indication of magnesia.

MANAGEMENT OF TIMBER after it is cut, p. 100.

MANNER OF DIVIDING a Gothic vault into compartments, p. 82.

MANNER OF DIVIDING conical, spherical, and other vaults, into compartments and caissons, p. 82.

MANSARD ROOF.—A roof formed with an upper and under set of rafters on each side, the under set less and the upper set more inclined to the horizon. It is called a *mansard* roof from the name of the architect, François Mansard, who revived its use in France. It is called also a *curb-roof*, from the French *courber*, to bend, descriptive of the double inclination of its sides. See MANSARD ROOF, p. 140, and Plate XXVII.

MANTELPIECE, MANTLEPIECE.—The ornamental dressing or front to the mantle tree.

MANTLE-SHELF.—The work over a fire-place in front of the chimney.

MANTLE-TREE.—The lintel of a fire-place.

MAPLE.—Description and uses of, p. 113.

MARBLE.—The popular name of any species of calcareous stone or mineral, of a compact texture, and of a beautiful appearance, susceptible of a good polish. Marble is limestone, or a stone which may be calcined to lime, a carbonate of lime; but limestone is a more general name, comprehending the calcareous stones of an inferior texture, as well as those which admit a fine polish. The term is limited by mineralogists and geologists to the several varieties of carbonate of lime, which have more or less of a granular and crystalline texture. In sculpture, the term is applied to several compact or granular kinds of stone, susceptible of a very fine polish. The varieties of marble are exceedingly numerous, and greatly diversified in colour. In modern times, the quarries of Carrara, in Italy, almost supply the world with white marble. Of variegated marbles, there are many sorts found in this country of singular beauty. Marble is much used for statues, busts, pillars, chimney-pieces, monuments, &c.

MARGIN DRAUGHT.—In stone cutting, a line of chiselling along the edge of a stone.

MARGIN OF A COURSE.—In slating, that part of a course of slating which is not covered by the next superior course.

MARGINS, OR MARGENTS.—The flat parts of the styles and rails of framed or panelled work. Doors which are made in two leaves are called *double-margined* doors, in consequence of the styles being repeated in the centre, as are also those in one leaf, made in imitation of a two-leaved door.

MARIGOLD WINDOW.—The same as *catherine wheel window* and *rose window*. See ROSE WINDOW.

MARKET-CROSS.—A cross set up where a market is held. Most market towns in England and Scotland had, in early times, one of these. The primitive form was that of simple shaft and cross stone, but they afterwards were constructed in a much more elaborate manner, so as frequently to lose the cruciform structure as a distinguishing characteristic.

MARL BRICKS.—Fine bricks used for gauged arches and the fronts of buildings.

MARQUETRY.—Inlaid work consisting of thin pieces of wood of different colours, arranged on a ground so as to form various figures. Used in cabinet work. The term is also used as synonymous with *mosaic*.

MASK.—A piece of sculpture representing some grotesque form, to fill and adorn vacant places, as in friezes, panels of doors, keys of arches, &c.

MASON.—One who prepares and sets stones; a builder in stone.

MASONRY.—The art of shaping, arranging, and uniting stones together to form walls and other parts of buildings.

MASTIC.—A kind of cement made by mixing litharge, or the red protoxide of lead, with pulverized calcareous stones, sand, and linseed oil. The proportions of the ingredients vary.

MATCH PLANES. Planes in pairs, used in joining boards by grooving and tonguing, one plane being used to form the groove, and the other to form the tongue.

MAUSOLEUM.—In modern times, a sepulchral chapel, or edifice erected for the reception of a monument, or to contain tombs.

MEANDER. An ornament composed of two

Meander

or more fillet mouldings intertwined in various ways; a fret.

MEDALLION.—A circular, oval, or sometimes square tablet, bearing on it objects represented in relief, or an inscription.

MEDIÆVAL ARCHITECTURE.—A term properly applied to denote the architecture which prevailed throughout the middle ages, or from the fifth to the fifteenth century. It thus comprises the Romanesque, the Byzantine, the Saracenic, the Lombard, and other styles, besides the Norman and the Gothic. In popular language, however, it is restricted to the Norman and early Gothic styles, which prevailed in Great Britain and on the Continent from the eleventh to the fourteenth century.

MEMBER.—Any subordinate part of a building, order, or composition, as a frieze or cornice; and any subordinate part of these, as a corona, a cymatium, a fillet.

MEMEL TIMBER, CROWN MEMEL, BEST MIDDLING, SECOND MIDDLING, OR BRACK. PINUS SYLVESTRIS, p. 116, 117.

MERLON.—The plain parts of an embattled parapet, between the crenelles or embrasures. See woodcut, BATTLEMENT.

METHODS OF PILING newly-felled timber, p. 100.

METOPE.—The space between the triglyphs of the Doric frieze.

METRE.—A French measure equal to 39·37 English inches.

MEZZANINE.—A story of small height introduced between two higher ones.

MEZZO-RELIEVO. — Middle relief. See DEMI-RELIEVO.

MIDDLE PANEL. p. 186.

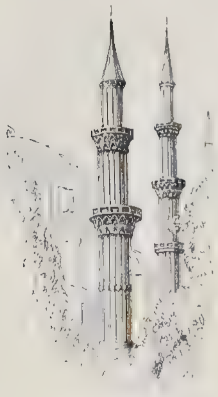
MIDDLE POST.—The same as *king-post*. The rail of a door level with the hand, and on which the lock is generally fixed; whence it is usually termed the *lock-rail*.

MILE.—A measure of distance. The English mile = 5280 feet; the geographical or nautical, 6075·6 feet; ratio of geographical to English, 1·15068 to 1.

MILLED LEAD.—Lead rolled out into sheets by machinery.

MILLIARY COLUMN.—A column set up to mark distances; a milestone. See COLUMN.

MINARET.—A slender, lofty turret rising by different stages or stories, surrounded by one or more projecting balconies, common in mosques in



Minarets, Constantinople

Mahometan countries. The priests from the balconies summon the people to prayers at stated times of the day; so that they answer the purpose of belfries in Christian churches.

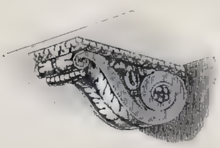
MINSTER.—A monastery; an ecclesiastical convent or fraternity; but it is said originally to have been the church of a monastery; a cathedral church. Both in Germany and England this title is given to several large cathedrals; as *York minster*, the *minster of Strasburg*, &c. It is also found in the names of several places which owe their origin to a monastery; as, *Westminster*, *Leominster*, &c.

MITRE.—The line formed by the meeting of surfaces or solids at an angle. It is commonly applied, however, when the objects meet in a right angle, and the mitre-line bisecting this makes an angle of 45° with both.

MITRE-BOX.—A box or trough with three sides, used for forming mitre joints. It has cuts in its vertical sides, the plane passing through which crosses the box at an angle of 45°. The piece of wood to be mitred is laid in the box, and the saw being worked through the guide-cuts, forms the mitre-joint in the wood.

MITRE-SQUARE.—A bevel with a fixed blade, for striking an angle of 45° on a piece of stuff, in order to its being mitred.

MODILLION.—A block carved into the form of an enriched bracket, used under the corona of the Corinthian and Composite entablatures. Modillions less ornate are occasionally used in the Ionic



Modillion.

entablature. The derivation of the word is probably from *modulus* (a measure of proportion), expressive of the arrangement of the brackets at regulated distances.

MODULAR PROPORTION.—That which is regulated by the module.

MODULE, MODULUS.—A measure which may be taken at pleasure to regulate the proportions of an order, or the disposition of the whole building. The diameter or semi-diameter of the column at the bottom of the shaft has usually been selected by architects as their module, and this they subdivide into parts or minutes, the diameter generally into sixty, and the semi-diameter into thirty minutes. Some architects make no certain or stated divisions of the module, but divide it into as many parts as may be deemed requisite.

MONASTERY.—A house of religious retirement or seclusion from ordinary temporal concerns, whether an abbey, a priory, a nunnery, or a convent. The word is usually applied to the houses of monks.

MONIAL, OR MONYCALE. See MULLION.

MONKEY.—The ram or weight of a pile-driving engine. See FISTUCA.

MONOCOTYLEDONOUS PLANTS. p. 93.

MONOLITHIC.—Formed of a single stone; as a *monolithic* obelisk.

MONOPTEROS.—A term used by Vitruvius to denote a temple composed of columns arranged in a circle, and supporting a conical roof or a tholus, but having no cella. Such a temple, however, would be more correctly denominated *cyclostylar*.

MONOTRIGLYPH.—The intercolumniation of the Grecian Doric most usually followed. It is that in which space is left for the insertion of only one triglyph between those immediately over two contiguous columns.

MONTANTS, MOUNTINGS, MUNTINS.—The intermediate styles in a piece of framing, which are tenoned into the rails. See p. 186.

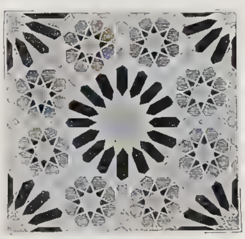
MOORISH, OR MORESQUE ARCHITECTURE. See SARACENIC ARCHITECTURE.

MORTAR.—A mixture of lime and sand with water, used as a cement for uniting stones and bricks in walls. The proportions vary from $1\frac{1}{2}$ part of sand to 1 part of lime, to 4 and 5 parts of sand to 1 of lime. When limestones contain considerable portions of silica and alumina, they form what is termed *hydraulic lime*, and the mortars made with them are called *hydraulic mortars*, which are used for building piers or walls under water, or exposed to it, because they soon harden in such situations, and resist the action of the water.

MORTISE, MORTICE.—A cavity cut in a piece of wood or other material, to receive a corresponding projecting piece called a *tenon*, formed on another piece of wood, &c., in order to fix the two together at a given angle. The sides of the mortise are four planes, generally at right angles to each other and to the surface where the cavity is made. The junction of two pieces in this manner is termed a *mortise joint*. See p. 147, JOINTS, and p. 182.

MORTISE LOCK.—A lock made to fit into a mortise cut in the style and rail of a door to receive it.

MOSAIC WORK is an assemblage of little pieces of glass, marble, precious stones, &c., of various colours, cut square, and cemented on a ground of stucco, in such a manner as to imitate the colours and gradations of painting. This kind of work was



Mosaic Pavement.

used in ancient times both for pavements and ornamenting walls. In recent times, two kinds of mosaic are particularly famous—the Roman and the Florentine. In the former, the pictures are formed by joining very small pieces of stone. In the Florentine style larger pieces are used.

MOUCHARABY.—A balcony with a parapet and machicolations projected over a gate to defend the entrance. The parapet may be either embattled or plain.

MOULD-STONE.—The jamb stone of an aperture.

MOULDED NOSING. p. 196.

MOULDING, OR FORMING THE SURFACE of wood into various square and curved contours, p. 184.

MOULDING PLANES.—Joiners' planes used in forming the contours of mouldings.

MOULDINGS, GOTHIC.—Examples of, p. 180.

MOULDINGS, GREEK AND ROMAN.—Mode of describing the various, p. 178.

MOULDINGS, PLANTED OR LAID IN, p. 185.

MOULDINGS, STUCK, p. 184.

MULLION, MUNNION, MONYCALE, MONIAL.—A vertical division between the lights of windows, screens, &c., in Gothic architecture. Mullions are rarely found earlier than the early English style. Their mouldings are very various. Sometimes the *styles* in wainscotting are called mullions.

MUTULE.—An ornament in the Doric cornice, answering to the modillion in the Corinthian, but differing from it in form, being a square block, from which the guttæ depend.

N.

NAIL.—A small pointed piece of metal, usually with a head, to be driven into a board or other piece of timber, and serving to fasten it to other timber. The larger kinds of instruments of this sort are called *spikes*; and a long, thin kind, with a flattish head, is called a *brad*. Nails are extensively used in building, and generally in the constructive arts. There are three leading distinctions of iron nails, as respects the state of the metal from which they are prepared, namely, *wrought* or *forged* iron nails, *cut* or *pressed* iron nails, and *cast* iron nails. Of the wrought or forged nails there are about 300 sorts, which receive different names, expressing for the most part the uses to which they are applied, as *hurdle*, *pail*, *deck*, *scupper*, *mop*, &c. Some are distinguished by names expressive of their form: thus, *rose*, *clasp*, *diamond*, &c., indicate the form of their heads, and *flat*, *sharp*, *spear*, &c., their points. The thickness of any specified form is expressed by the terms *fine*, *bastard*, *strong*. Nails are made both by hand and by machinery.

NAIL-HEAD MOULDING.—An ornament common in Norman architecture. It is so named from being formed by a series of diamond-pointed knobs, resembling the heads of nails.

NAILS, ADHESION OF, in Wood. See ADHESIVE FORCE of Nails and Screws.

NAKED.—Any continuous surface, as opposed to the ornaments and projections which arise from it. Thus the naked of a wall is the continuous surface of the wall, as opposed to its projections or ornamented parts.

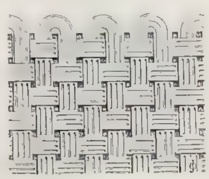
NAKED FLOORING.—The supporting timbers on which the floor-boards are laid. See p. 150.

NAOS.—The body of an ancient temple, sometimes, but erroneously, applied to the cella or interior. The space in front of the temple was called *pronaos*.

NARTHEX.—The name of an inclosed space in the ancient basilicæ when used as Christian churches, and also of an ante-temple or vestibule without the church. To the narthex the catechumens and penitents were admitted; and there appears to have been several such apartments in each church, but nothing certain is known of their position. Narthex is frequently used as synonymous with *porch* and *portico*.

NARVA TIMBER.—PINUS SYLVESTRIS, p. 116, 117.

NATTES.—A name given to an ornament used in the decoration of surfaces in the architecture of



Nattes, Bayeux Cathedral.

the twelfth century, from its resemblance to the interlaced withs of matting.

NATURAL BEDS OF STONE are the surfaces

in stratified rocks, in which the laminæ separate. As all stones of this kind exfoliate rapidly when these surfaces are exposed, it becomes necessary, in using them in building, to lay them on their natural beds, or, in other words, so to place them in the wall that their exfoliating surfaces shall be horizontal, or at right angles to its face. The contrary use of the stone is described as *setting on edge*.

NAVE.—The central avenue or middle part of a church, extending from the western porch to the transept, or to the choir or chancel, according to the nature and extent of the church. In the larger structures it has generally one or more aisles on each side, and sometimes a series of small chapels beyond these. In smaller buildings it is commonly without aisles. See woodcut, CATHEDRAL.

NEBULE MOULDING.—A moulding whose edge takes the form of an undulating line. It is used in corbel tables and archivolts.

NECK, NECKING, OR HYPOTRACHELIUM.—In architecture, the part which serves to connect a capital or head with its body or shaft; thus the *neck of a capital* is that part which lies between the lowest moulding of the capital and the highest moulding of the shaft. In the Grecian Doric it is the space between the annulets and the channel, and in the Roman Doric it is the space between the annulets and the astragal. In the same way the neck of a finial is the part in which the finial joins the obelisk, and the channels, astragals, or other members which terminate the shaft or body, are called the *neck mouldings*.

NECK-MOULDINGS. See preceding word.

NEEDLE.—A beam of timber supported on upright posts, used to carry a wall temporarily during alterations or repairs.

NEEDLEWORK.—A term sometimes applied to the framework of timber, of which old houses are constructed.

NERVURES, NERVES, OR BRANCHES. The ribs which bound the sides of a groined compartment in a vaulted roof, as distinguished from the diagonal ribs.

NEUTRAL AXIS.—That plane in a beam in which theoretically the tensile and compressive forces terminate, and in which the stress is therefore nothing. See STRENGTH AND STRAIN OF MATERIALS Transverse Strain, p. 126.

NEWEL.—The upright cylinder or pillar, round which, in a winding staircase, the steps turn, and are supported from the bottom to the top. In stairs where the steps are pinned into the wall and there is no central pillar, the staircase is said to have an *open newel*. The newel is sometimes continued through to the roof, and serves as a vaulting-shaft from which the ribs branch off in all directions.

NEWEL STAIRS, p. 196.

NICHE.—A recess in a wall for the reception of a statue, a vase, or of some other ornament. In classic architecture, niches were generally semicircular in the plan, and terminated in a semi-dome at the top. They were sometimes, however, square in the plan, and sometimes also square-headed. They were ornamented with pillars, architraves, consoles, and in other ways. In the architecture

Niche, All-Souls' College, Oxford

of the middle ages niches were extensively used as decorations, and for the reception of statues. In the Norman style they were so shallow as to be little more than panels, and the figures were frequently carved on the back in alto-rilievo. In the early English style they become more deeply recessed, and are highly enriched, and in the Decorated style they become infinitely varied. They were chiefly semi octagonal or semi-hexagonal in plan, and their heads were formed into groined vaults, with ribs, and bosses, and pendants. They were projected on corbels, and adorned with pillars, buttresses, and mouldings of various kinds, and had canopies added to them, sometimes flat and sometimes projecting in every variety of plan, and elaborately carved and enriched. In the Perpendicular style this variety and elaboration were continued.

NICHE, SPHERICAL, on a circular plan, p. 83.

NICHE, SPHERICAL, on a segmental plan, p. 83.

NICHE, on a semicircular plan, with a segmental elevation, p. 83.

NICHE, segmental in plan and elevation, p. 84.

NICHE, segmental in plan and elliptical in elevation, p. 84.

NICHE, a, elliptical in plan and elevation, p. 84.

NICHE, a, octagonal in plan, p. 84.

NICHE, a semicircular, in a concave wall, p. 84.

NICHE, a semicircular, in a convex wall, p. 85.

NICHE, A. To determine the shadow in the interior of, p. 22.

NIDGING.—In masonry, nidging is a mode of dressing used chiefly for granite, but sometimes also applied to other stones. It is thus performed. The face of the stone being prepared as for rubbing or tooling, the beds and joints are squared up, and a margin draught, about ⅞ths of an inch wide, run round the face. Lines are then drawn around the margin, parallel with the beds and joints, and cut in by a sharp boaster, with light blows of the mallet. The nidging then begins. The tool used for this is a hammer about 3 lbs weight, having its ends formed like an axe. The axe-face of the hammer is held crossing the stone at right angles to its length; each blow makes a slight indentation by abrasion, and, by a succession of blows, the stone is furrowed all over with shallow furrows, and reduced to a uniform surface. No portion of stone should be left between the successive series of furrows. Nidging, when well done, is a characteristic mode of working hard stones; but it is not proper to be used for soft stones, as it makes their surface more liable to be acted on by the weather.

NOGGING.—Brick-work carried up in panels between timber quarters.

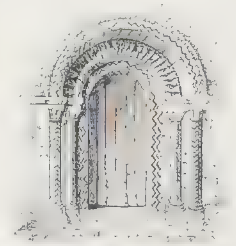
NOGGING PIECES.—Horizontal pieces fitted in between and nailed to the quarters for strengthening the brick-nogging.

NOGS.—A north of England term for wood bricks or timber bricks.

NONAGON.—A figure having nine sides and nine angles. To find the area of a nonagon. Multiply the square of its side by 6·181824.

NONIUS. See VERNIER.

NORMAN ARCHITECTURE.—A style of architecture imported into England immediately from Normandy, at the time of the Conquest, A.D. 1066. It continued in use till towards the end of the twelfth century, when it was superseded by the



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first of the Pointed or Gothic styles, the *Early English*. The Norman is readily distinguished from the styles which succeeded to it by its general massive character, round-headed doors and windows, and low square central tower. The doorways are generally very highly enriched by a profusion of decorated mouldings, for the most part peculiar to the style. The windows have no mullions, and in the early examples are quite plain. In later specimens they have frequently small shafts in the jambs, or are enriched with the zigzag moulding peculiar to the style. The piers which support the arches are in the earlier examples strikingly solid and massive, being merely plain square or circular masses of masonry, sometimes having capitals and bases, and sometimes merely an impost to relieve the outline. The square piers were frequently recessed at the angles, and in some cases had half pillars attached to their sides; and the circular ones in some instances had the plain surface relieved by lines cut in a lozenge or spiral form. As the style advanced, these solid piers were reduced to more moderate proportions of round or octagonal pillars, and in the time of the transition were frequently very tall and slender. The capitals of these piers and pillars are among the most important features of this style. The upper member or abacus is in general square, and

[illegible]

its profile is also square, having its lower edge sloped or *chamfered* off. One of the earliest forms of the capital, and which, with various modifications, is found in all periods of the style, is what is called the *cushion capital*. (See woodcut under that term.) It is frequently divided into two or more parts, and is also sometimes enriched with sculpture of foliage and figures; but under all these modifications it may still be taken as the primary form of the Norman capital. The arches were almost universally round-headed until the period of the transition, when the pointed form was used along with or frequently instead of it. The pointed arch must not be taken as a certain criterion of transition date, as we have examples of it combined with solid early Norman piers, as at Malmesbury Abbey; but these examples are rare, and the mixture of the two forms may generally be taken as evidence of transition. The windows were universally round headed, until the transition period.

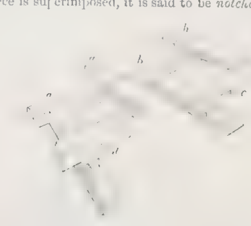
NORWAY SPRUCE.—Description and uses of, p. 117.

NORWAY TIMBER. See PINUS SYLVESTRIS, p. 116, 117.

NOSING.—The projecting edge of a moulding or drip.

NOSING OF STEPS.—The projecting moulding on the edge of a step, consisting generally of a torus, with a fillet below, joined by a sweep or cavetto to the face of the riser. See p. 196.

NOTCH, v.—To cut a hollow on the face of a piece of timber, for the reception of another piece. The piece in which the hollow is cut is said to be *notched upon* the other piece, and if the notched piece is superimposed, it is said to be *notched down*



upon the inserted piece; as the bridging joists are *notched down on* the binding-joists in naked flooring. (See p. 151.) The figures show the varieties of notching in common use. *a* is the method termed *halving*; that is, when a notch equal in depth to half the thickness of the stuff is made in both pieces; *b* is a dovetail notch; in *c* the notch is formed a little way from the end of each piece, so that the joint cannot be drawn asunder in either direction;

OVOLO.—A moulding, the vertical section of which is, in Roman architecture, a quarter of a circle; it is thence called the *quarter-round*. In Grecian architecture the section of the ovolo is elliptical, or rather egg-shaped.

OVOLO.—To describe an ovolo, its projection and a tangent to it being given, p. 179.

OVOLO, THE HYPERBOLIC.—To describe, its projection and a tangent to it being given, p. 179.

P.

PACE.—A portion of a floor slightly raised above the general level; a dais.

PACKING. In masonry, small stones imbedded in mortar, used to fill up the interstices of the larger stones in rubble walls.

PAD.—A handle

PADDLE.—A small sluice.—*Paddle-holes* are the passages which conduct the water from a dock or the upper pond of a canal, into the lock-chamber, and out of the lock-chamber into the lower pond.

PAGODA.—A temple in the East Indies, in which idols are worshipped. The pagoda is generally of three subdivisions. First, an apartment whose ceiling is a dome, resting on columns of stone or marble; this part is open to all persons. Second, an apartment forbidden to all but Brahmins. Third and last, the cell of the deity or idol inclosed with a massy gate. The idol itself is sometimes called a *pagoda*. The most remarkable pagodas are those of Benares, Siam, Pegu, and particularly that of Juggernaut in Orissa. Pagodas are also common in China, where they are called *taas*.

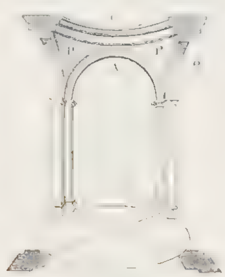
PALÆSTRA.—Among the Greeks, a place for athletic exercises.

PALLET MOULDING.—In brick-making, that kind of moulding in which sand is used to prevent the clay from adhering to the mould, one mould only being used; and the brick when moulded turned out on a flat board called a *pallet*, on which it is carried by the assistant to the hack-barrow or the hack.

PAMPRES.—Ornaments consisting of vine leaves and grapes, with which the hollows of the circumvolutions of twisted columns are sometimes decorated.

PAN OF WOOD, OR PAN OF FRAMING. See TIMBER HOUSES, p. 156.

PANACHE. The French name for a species of pendentive, formed by a portion of a domical vault intercepted between one horizontal and two vertical surfaces. It occurs when a round tower or dome is carried over a square substructure, as when



Panache

a dome is raised on the square formed by the crossing of the nave and transept of a church. In this case the panache P becomes a spherical triangle, bounded by three arcs, viz., the arch of the nave A, the arch of the transept B, and the circle C, which serves as the springing of the dome or tower.

PANEL.—In architecture, an area sunk from the general face of the surrounding work; also a compartment of a wainscot or ceiling, or of the surface of a wall, &c.; sometimes inclosing sculptured ornaments. In joinery, it is a tympanum or thin piece of wood, framed or received in a groove by two upright pieces or styles, and two transverse pieces or rails; as the *panels* of doors, window-shutters, &c. In masonry, a term sometimes applied to one of the faces of a hewn stone.

PANEL SAW.—A saw used for cutting very thin wood in the direction of the fibres or across them. Its blade is about 26 inches long, and it has about six teeth to the inch.

PANELLING.—In architecture, the operation of covering or ornamenting with panels; panelled work.

PANELS IN JOINERY, p. 185.

PANTAGRAPH, PANTOGRAPH.—An instrument for copying, enlarging, or reducing drawings. See EIDOGRAPH.

PANTHEON.—A temple dedicated to all the gods. The term is also applied to places of public exhibition, in which every variety of amusement is to be found.

PANTILE, OR PENTILE.—A tile in the form of a parallelogram, straight in the direction of its length, but with a waved surface transversely. Each tile is about 13½ inches long and 7 inches wide, but the development of its surface is of course greater; it is about half an inch thick. It has a small tongue or projection from its under side at its upper end, which serves to hook it to the lath. Pantiles are set either dry or in mortar. They overlap laterally, the down bent edge of the one tile covering the upturned edge of the other. Having only 3 or 4 inches of longitudinal overlap, pantiling is little more than half the weight of plain tiling, but it is not so warm a covering, and is more apt to be injured by storms. The ridges and hips of roofs covered either with pan or plain tiles, are finished with large concave tiles, called *hip* or *ridge* tiles, and sometimes *crown* tiles, these are not over lapped, but are set in mortar and fastened with nails or pins. To find the number of pantiles required to cover a roof, the gauge being 10 inches. Rule: Multiply the area in superficial feet by 1·80. And to find the weight in tons. Multiply the area in superficial feet by ·00377.

PARABOLA.—Description of the, p. 26.

PARABOLA.—To draw, p. 26.

PARABOLA. To draw by means of intersecting lines, Prob. XCVII. and XCVIII. p. 27.

PARABOLA.—To draw, by means of a straight rule and a square, Prob. XCIX. p. 27

PARABOLA.—To find the parameter of a parabola, p. 26.

PARABOLA.—To draw perpendiculars to the curve of a parabola, p. 26.

PARABOLA.—To find the area of a parabola or its segment. Multiply the base by the perpendicular height, and two-thirds of the product is the area.

PARADISE.—In mediæval architecture, a small private apartment or study.

PARALLEL.—To draw a straight line parallel to a given straight line, Prob. I. and II. p. 5.

PARALLEL COPING.—Coping of equal thickness throughout.

PARALLEL PERSPECTIVE.—That in which the picture is supposed to be situated, so as to be parallel to the side of the principal object to be represented. See PERSPECTIVE, p. 227.

PARALLELOGRAM.—To inscribe in a given quadrilateral figure, Prob. XXXIII. p. 11.

PARALLELOGRAM OF FORCES, p. 120.

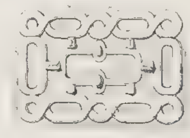
PARALLELOGRAM OF FORCES.—Application of, to discover the stress on parts of framing, p. 121.

PARAPET.—Literally, a wall or rampart to the breast, or breast high.—In military structures, the parapet is a wall intended for defence, and is either plain or battlemented, and pierced with loop-holes and oillets for the discharge of missiles.—In civil and ecclesiastical buildings, the parapet, like the balustrade, is to be regarded chiefly in the light of an ornament. The plain and simple embattled parapet, indeed, is to be found in buildings of the middle ages, from the early Norman to the latest Perpendicular; but, in general, the parapet assumes the character of the various styles, proceeding from comparative plainness in the earlier styles, to being ornamented with panelled and pierced work in those which succeeded it.—In common language, a parapet is a breast-wall raised on the sides of bridges, quays, &c., for protection.

PARGE BOARD.—See BARGE BOARD.

PARGET.—1. Gypsum; plaster stone.—2. Plaster laid on roofs or walls.—3. A plaster formed of lime, hair, and cow-dung, used for plastering flues.

PARGETTING, PERGETTING, PERGEURING, PARGE-WORK.—Plastering; as a noun, plaster or stucco. Also, a term used for plaster-work of various kinds, but commonly applied to a particular sort of plaster-work, with patterns and ornaments raised or indented upon it, much used in the interior, and often in the exterior of houses in the time of Queen Elizabeth. The term is now seldom used, except for the plastering of chimney flues.



Pargetting

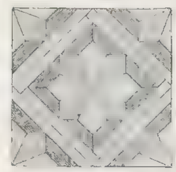
PARING CHISEL.—A broad, flat chisel used by joiners; it is worked by the impulsion of the hand alone, and not by the blows of a mallet, like the socket chisel, firmer, &c.

PARK AND ENTRANCE GATES, p. 177.

PARPEND, OR PERPEND.—A stone reaching through the thickness of a wall so as to be visible on both sides, and therefore worked on both ends.

PARPEND WALL.—A wall built of parpends or stones which reach through its entire thickness.

PARQUETRY.—A species of joinery or cabinet-work, which consists in making an inlaid floor composed of small pieces of wood, either square or triangular, which, by the manner of their disposition, are capable of forming various combinations of figures. Such floors are much used in France.



Parquetry

PARREL. A chimney-piece; the dressings and ornaments of a fireplace.

PARTHENON.—A celebrated Grecian temple of Minerva in the Acropolis of Athens. It was built of marble, and was a peripteral octostyle, with 17 columns on the sides; its length 223 feet, breadth 102, and height from the base to the pediment 65 feet. It was almost reduced to ruins in 1687 by the explosion of a quantity of gunpowder which the Turks had placed in it; but dilapidated as it now is, it still retains an air of inexpressible grandeur and sublimity.

PARTING BEAD.—The beaded slip inserted into the centre of the pulley-style of a window, to keep apart the upper and lower sashes.

PARTITION.—A wall of stone, brick, or timber, which serves to divide one apartment from another in a building.

PARTITIONS, TIMBER, p. 158.

PARTY-WALLS.—A wall formed between houses to separate them from each other, and prevent the spreading of fire.

PATAND, PATIN.—1. A piece of timber laid on the ground to receive and sustain the ends of vertical pieces.—2. A bottom plate; a sill.

PATERA.—1. An open vessel in the form of a cup, used by the Greeks and Romans in their sacrifices and libations.—2. The representation of a cup or round dish in flat relief, used as an ornament in friezes; but many flat ornaments are called pateras which have no resemblance to cups or dishes.

PATTEN.—The base of a column or pillar.

PAVILION.—1. A turret or small building, usually isolated, and having a tent-formed roof,

Pavilion of Flora, Tuileries, Paris.

whence its name.—2. A projecting part of a building, when it is carried higher than the general structure, and provided with a tent-formed roof.

PEAR TREE.—Description of the properties and uses of, p. 114.

PECKINGS. See PLACE-BRICKS.

PECKY.—A term in America applied to timber in which the first symptoms of decay appear.

PEDESTAL.—An insulated basement or support for a column, a statue, or a vase. It usually consists of a base, a die or dado, and a cornice, called also a *surbase* or *cap*. When a range of columns is supported on a continuous pedestal the latter is called a *podium* or *stylobate*.

PEDIMENT.—In classic architecture, the triangular finishing above the entablature at the end of buildings or over porticoes. The mouldings of the entablature bound the inclined sides of the pediment. Also the triangular finishing over doors and windows. In the debased Roman style the same name is given to these same parts, though not triangular in their form, but circular, elliptical, or interrupted. In the architecture of the middle ages, small gables and triangular decorations over openings, niches, &c., are called pediments. These have the angle at the apex more acute than the corresponding decoration of classic architecture.

PEEN.—The same as *piend* (which see).

PENCILS.—Qualities and uses of, p. 45.

PENDANT, PENDENT.—A hanging ornament used in the vaults and timber roofs of Gothic architecture. In the former, pendants are formed of stone and generally richly sculptured, and in timber-work they are of wood, variously decorated with carving. See Plate XXXI.

PENDANT POST.—1. In a mediæval principal roof-truss, a short post placed against the wall, its lower end supported on a corbel or capital, and its upper end carrying the tie-beam or hammer-beam.—2. The support of an arch across the angles of a square.

PENDENTIVE.—The portion of a dome-shaped vault, which descends into a corner of an angular building, when a ceiling of this kind is

Pendentive Roof

placed over a straight-sided area. Thus, when a portion of a sphere, as the hemisphere in the figure, is intersected by cylindrical or cylindroidal arches, as *a a a*, the vaults *b b* are formed, which are pendentives. In Gothic architecture, the portion of a groined ceiling springing from one pillar or impost, and bounded by the apices of the longitudinal and transverse vaults, is called a *pendentive*.

PENDENTIVE of an irregular octagonal plan over an apartment, the plan of which is a parallelogram, p. 82.

PENDENTIVE formed by the intersection of an octagonal domical vault with a square, p. 81.

PENDENTIVE BRACKETING.—The coved bracketing springing from the wall of a rectangular area in an upward direction, so as to form the horizontal plane into a complete circle or ellipse. See PENDENTIVE.

PENDENTIVE CRADLING.—The timber work for sustaining the lath and plaster in pendentives.

PENT-HOUSE.—A shed with a roof of a single slope.

PENT-ROOF.—A roof formed like an inclined plane, the slope being all on one side; called also a *shed-roof*.

PENTADORON. In ancient architecture, a brick of five palms in length, used by the Greeks in the construction of their sacred edifices.

PENTAGON.—A figure with five equal sides and angles is a regular pentagon; if the sides be unequal, it is an irregular pentagon.—To find the area of a regular pentagon. Multiply the square of its side by 1·7204774.

PENTAGON.—On a given straight line, to describe a regular pentagon, Prob. XXXVIII. p. 12.

PENTAGRAPH. See PANTAGRAPH.

PENTASTYLE.—An edifice having five column in front.

PERCH.—An old name sometimes applied to a bracket or corbel.

PERCLOSE, PARCLOSE.—The raised carved timber back to a bench or seat; the parapet round a gallery; a screen or partition.

PERGETTING, OR PERGEURING. See PARGETTING.

PERIBOLUS.—In ancient architecture, a court surrounding a temple, and itself surrounded by a wall inclosing the whole of the sacred ground. It was commonly adorned with statues, altars, and monuments, and sometimes contained other smaller temples or a sacred grove. A perfect example of the peribolus exists in the temple of Isis at Pompeii, and remains of others are found at Palmyra and elsewhere.

PERIDROMUS.—The space in a peripteral temple, between the walls of the cella or body and the surrounding columns.

PERIMETER.—The circuit or boundary of any plane figure. In round figures it is equivalent to *circumference* or *periphery*, but the term is more frequently applied to figures composed of straight lines.

PERIPHERY.—The circumference of a circle or ellipse, or of any curvilinear figure.

PERIPTERAL.—A temple, the cella of which is surrounded with columns, those on the flanks being at a distance from the wall equal to their intercolumniation.

PERISTYLE, PERISTYLIUM.—A range of columns surrounding anything, as the cella of a temple, or any place, as a court or cloister. It is frequently but incorrectly limited in signification to a range of columns round the interior of a place.

PERPEND, PERPYN, PERPENT. See PARPEND.

PERPENDICULAR LINES.—To erect or let fall, p. 6–18.

PERPENDICULAR STYLE.—The third and last of the pointed or Gothic styles used in this country, called also the *florid* style of Gothic. It was developed from the Decorated during the latter part of the fourteenth century, and continued in use till the middle of the sixteenth. The broad distinction between this and the preceding styles lies in the preponderance of perpendicular lines, particularly observable in the tracery of windows, the panelling of flat surfaces within and without, and the multiplicity of small shafts with which the piers, &c., are overlaid. The vertical line everywhere predominates, catching the eye at first sight, so that when once this characteristic has been pointed out, it is impossible to mistake a building in this style. Another peculiarity is the increased width of the windows and the lowness of the roofs, which are frequently so low as not to rise above the parapet. This is owing to the use of the four-centred depressed arch, which gave an opportunity of employing greater width, without increasing the height of the windows. To such an extent is this peculiarity carried, that the chancel of a church in this style is almost as light as a conservatory, the whole space between the buttresses being occupied with the windows. The upper tier of windows, or clear-story, offers another peculiarity. In the preceding styles these windows were generally small; but in the Perpendicular, when that style became fully developed, they are often so large, and placed so closely together, that the whole clear-story becomes one large window, merely divided by the mullions. The annexed view of Beauchamp Chapel presents a very perfect instance of Perpendicular architecture, both in the windows, and also in the panelling, parapets, buttresses, and turrets. It will be seen that the principal mullions, instead of running into flowing tracery, are here carried straight through to the head of the window, and that the subordinate tracery is likewise converted into straight lines. In this consists the essential difference between the Decorated and Perpendicular styles. The Perpendicular style of Gothic architecture was peculiar to England.

East End of the Beauchamp Chapel, Warwick

PERPENT-STONE. See PARPEND.

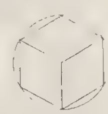
PERRON.—A term denoting a staircase lying open or outside the building; or more properly the steps in the front of a building which lead into the first story, where it is raised a little above the level of the ground.

PERSIAN.—A figure in place of a column, used to support an entablature. See CARYATIDES.

PERSPECTIVE.—1. The science which teaches the representation of an object or objects on a definite surface, so as to affect the eye when viewed from a given point, in the same manner as the object or objects themselves. Correctly defined, a perspective delineation is a section, by the plane or other surface, on which the delineation is made, of the cone of rays proceeding from every part of the object to the eye of the spectator. It is intimately connected with the arts of design, and is indispensable in architecture, engineering, fortification, sculpture, and generally all the mechanical arts; but it is particularly necessary in the art of painting, as without a correct observance of the rules of perspective, no picture can have truth and life. Perspective alone enables us to represent foreshortenings with accuracy, and it is requisite in delineating even the simplest positions of objects. Perspective is divided into two branches, *linear* and *aerial*. *Linear perspective* has reference to the position, form, magnitude, &c., of the several lines or contours of objects, &c. The outlines of such objects as buildings, machinery, and most works of human labour which consist of geometrical forms, or which can be reduced to them, may be most accurately obtained by the rules of linear perspective, since the intersection with an interposed plane of the rays of light proceeding from every point of such objects, may be obtained by the principles of geometry. Linear perspective includes the various kinds of projections; as *scenographic, orthographic, ichnographic, stereographic* projections, &c. *Aerial perspective* teaches how to give due diminution to the strength of light, shade, and colours of objects according to their distances, and the quantity of light falling on them, and to the medium through which they are seen.—*Perspective plane*, the surface on which the object or picture is delineated, or it is the transparent surface or plane through which we suppose objects to be viewed; it is also termed the *plane of projection*, and the plane of the picture.—*Parallel perspective* is where the picture is supposed to be so situated, as to be parallel to the side

Oblique Perspective   Parallel Perspective

of the principal object in the picture; as a building, for instance.—*Oblique perspective* is when the plane of the picture is supposed to stand oblique to the sides of the object represented; in which case the representations of the lines upon those sides will not be parallel among themselves, but will tend towards their vanishing point.—2. A kind of painting, often seen in gardens and at the end of a gallery, designed expressly to deceive the sight by representing the continuation of an alley, a building, a landscape, or the like.—*Isometrical perspective*, or more correctly *isometrical projection*, a kind of orthographic projection, so named and brought prominently into notice by Professor Farish, of Cambridge, by which solids, of the form of rectangular parallelopipeds, or such as are reducible to this form, or can be contained in it, can be represented with three of their contiguous planes in one figure, which gives a more intelligible idea of their form than can be done by a separate plan and elevation. At the same time, this method admits of their dimensions being



measured by a scale as directly as in the usual mode of delineation. As applied to buildings and machinery, it gives the elevation and ground plan

Isometrical Perspective

in one view, and is therefore considered more useful, as explanatory of the ordinary geometrical drawings, than linear perspective. It is also easier and simpler in its application.

PERSPECTIVE.—Introductory observations, p. 227.

PERSPECTIVE. — Definitions of terms, p 228, 229.

PERSPECTIVE. -To find the perspective of a given point, Prob. I. p. 229.

PERSPECTIVE.—To find the perspective of a given right line, Prob. II. p 229.

PERSPECTIVE.—Rules in, p. 229–232.

PERSPECTIVE.—The distance of the picture and the perspective of the side of a square being given, to complete the square without having recourse to a plan, Prob. III. p. 233.

PERSPECTIVE. -To divide a line given in perspective in any proportion, Prob. IV. p. 234.

PERSPECTIVE Through a given point in a picture, to draw a line parallel to the base or side of the picture, and perspectively equal to another given line, Prob. V. p. 234.

PERSPECTIVE —To draw the perspective of a pavement of squares, Prob. VI.-VIII. p. 235.

PERSPECTIVE.—To draw a hexagonal pavement in perspective, Prob. IX. p. 236.

PERSPECTIVE.—To draw the perspective of a circle, Prob. X. p. 236.

PERSPECTIVE. -To inscribe a circle in a square given in perspective, Prob. XI. p. 236.

PERSPECTIVE. -To draw a tetrahedron in perspective, Prob. XII. p. 237.

PERSPECTIVE.—To draw a cross in perspective, p. 241.

PERSPECTIVE.—To draw a pavilion in perspective, p. 241.

PERSPECTIVE.—To draw a broach or spire in perspective, p. 242. 243, Plate CVII. and CXI

PERSPECTIVE. -To draw a Tuscan gateway in perspective, p 242, Plate CIX

PERSPECTIVE.—To draw a Turkish bath in perspective, p. 243, Plate CX.

PERSPECTIVE. -To draw a series of arches in perspective, p. 242, Plate CVIII.

PERSPECTIVE. -To draw a circular vault pierced by a circular headed window in perspective p. 242, Plate CVIII.

PERSPECTIVE.—Isometric projection, definition and illustration of, p 242.

PERSPECTIVE. -Isometric scales, how to construct, p. 243.

PERSPECTIVE. -Isometrical projection, application of, to curved lines, p 245

PERSPECTIVE. — To draw a cube in perspective, Prob. XIII. p. 237.

PERSPECTIVE.—To draw cylinders in perspective, Prob. XIV. p. 238.

PERSPECTIVE.—Proper angle at which objects should be viewed, p. 238.

PERSPECTIVE.—Argument against the use of the distinctive terms *parallel* and *oblique* perspective, p. 239.

PERSPECTIVE.—To draw a sphere in perspective, Prob XV. p. 239.

PERSPECTIVE.—Practical examples of perspective drawing applied to architecture, &c., p. 240.

PETERSBURG TIMBER. See PINUS SYLVESTRIS, p. 116, 117.

PEW DOOR, Plate LXXIII. Fig. 6, p. 187.

PHOLAS.—A marine animal, injurious to timber, p. 105.

PIAZZA.—A square open space surrounded by buildings or colonnades. The term is frequently, but improperly, used to signify an arcaded or colonnaded walk.

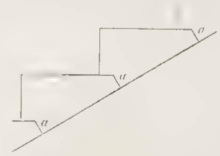
PIECE-WORK.—Work done and paid for by the measure of quantity, in contradistinction to work done and paid for by the measure of time.

PIEDOUCHE.—A small pedestal or base, serving to support a bust, candelabrum, or other ornament.

PIEDROIT.—The jamb of an opening, including the face and retiring side. It is more specifically applied to the jamb of an arched opening, when crowned with an impost moulding.

PIEND.—An arris; a salient angle; a hip.

PIEND CHECK. -A term applied in Scotland to the rebate formed on the piend or angle at



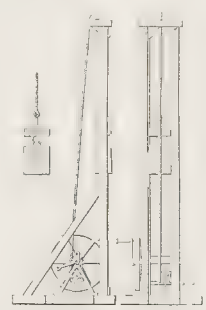
the bottom of the riser of the stone step of a stair, as at *a a a* in the figure.

PIER.—1. The support of the arches of a bridge; the solid parts between openings in a wall, such as the door, windows, &c. (See woodcut, ARCH.)—2. A mole or jetty carried out into the sea, whether intended to serve as an embankment to protect vessels from the open sea, or merely as a landing place. For this latter purpose suspension chain-piers are sometimes employed.—3. The pillars in Norman and Gothic architecture are generally, though not very correctly, termed *piers*.

PIER-ARCHES. - In Gothic architecture, arches supported on piers (or pillars) between the central parts and aisles of a church.

PILASTER.—A debased pillar; a square pillar projecting from a pier or from a wall, to the extent of from one fourth to one third of its breadth. Pilasters originated in the Grecian antæ. In Roman architecture they were sometimes tapered like columns, and finished with capitals modelled after the order with which they were used.

PILE-DRIVER, OR PILE-ENGINE. An engine for driving down piles. It consists of a large ram or block of iron, termed the *monkey*, which slides between two guide posts. Being drawn up to the



Pile-driver

top, and then let fall from a considerable height, it comes down on the head of the pile with a violent blow. It may be worked by men or horses, or a steam engine. The most improved pile driver is that constructed by Mr. James Nasmyth, being an ingenious application of the principle of his celebrated steam hammer

PILE-PLANKS.—Planks about 9 inches broad, and from 2 to 4 inches thick, sharpened at their lower end, and driven with their edges close together into the ground in hydraulic works. Two rows of pile-planks thus driven, with a space between them filled with puddle, is the means used to form water-tight coffer dams and similar erections.

PILES.—Beams of timber, pointed at the end, driven into the soil for the support of some superstructure. They are either driven through a compressible stratum, till they meet with one that is incompressible, and thus transmit the weight of the structure erected on the softer to the more solid material, or they are driven into a soft or compressible structure in such numbers as to solidify it. In the first instance, the piles are from 9 to 18 inches in diameter, and about twenty times their diameter in length. They are pointed with iron at their lower end, and their head is encircled with an iron ring, to prevent its being split by the blows of the pile driver. In the second case, the piles are from 6 to 12 feet long, and from 6 to 9 inches in diameter. In constructing coffer-dams and other hydraulic works, other kinds of piles besides those described are used, such as gauge piles, sheeting-piles, pile planks, key-piles. These will be found under their proper heads.

PILLAR.—1. A pile, or columnar mass composed of several pieces, and the form and proportions of which are arbitrary, that is, not subject to the rules of classic architecture. A square pillar is a massive work, called also a *pier* or *piedroit*, serving to support arches, &c.—2. A supporter; that which sustains or upholds; that on which some superstructure rests.

PIN.—A piece of wood or metal, square or cylindrical in section, and sharpened or pointed, used to fasten timbers together. Large metal pins are termed *bolts*, and the wooden pins used in ship-building *treenails*.

PINACOTHECA.—A picture gallery.

PINES AND FIRS.—Descriptions and uses of, p. 115, *et seq.*

PINNACLE.—1. A turret, or part of a building elevated above the main building.—2. In mediæval architecture, a term applied to any lesser

Early English Pinnacle, Beverley Minster.

Perpendicular Pinnacle, Trinity Ch., Cambridge

structure or ornament, consisting of a body or shaft terminated by a pyramid or spire, used either exteriorly or interiorly.

PINNING.—Fastening tiles or slates with pins; inserting small pieces of stone to fill vacuities.

PINNING UP. Driving in wedges in the process of underpinning, so as to bring the upper work to bear fully on the work below.

PINS-DRAWING. p. 45.

PINUS STROBUS. - The Weymouth pine, p. 118.

PINUS SYLVESTRIS. p. 116, 117.

PISCINA.—A niche on the south side of the altar in Roman Catholic churches, containing a small basin and water-drain, through which the

Piscina, Fifield, Essex

priest emptied the water in which he had washed his hands, and also that with which the chalice had been rinsed.

PISÉ.—A species of wall constructed of stiff earth or clay, rammed into moulds, which are carried up as the work is carried up. It has been used in

France of late years, but it is as old as the days of Pliny.

PITCH OF A ROOF.—The inclination of the sloping sides of a roof to the horizon, or the vertical angle formed by the sloping side. The pitch is usually designated by the ratio of the height to the span.

PITCH OF A ROOF.—Opinions of various authors as to the pitch which should be given to a roof, to suit the climate and the material used for covering, p. 134, 135.

PITCH PINE.—Properties and uses of, p. 118.

PITCH PINE. p. 118.

PITCHING PIECE. p. 196.

PITCHING PIECE.—A piece of timber projecting horizontally from a wall, to support the rough strings in staircasing. See APRON-PIECE.

PLACE BRICKS.—Those bricks which, having been outermost or farthest from the fire in the clamp or kiln, have not received sufficient heat to burn them thoroughly. They are consequently soft, uneven in texture, and of a red colour. They are also termed *peckings*, and sometimes *sandel* or *samel bricks*.

PLAFOND, PLATFOND.—1. The ceiling of a room, whether flat or arched.—2. The under side of a cornice.—3. Generally, any soffit.

PLAIN TILES are simple parallelograms, generally about $10\frac{1}{2}$ inches long, $6\frac{1}{2}$ inches wide, and $\frac{5}{8}$-inch thick, and weighs 2 lbs. 5 oz. Each tile has a hole at one end to receive the wooden pin by which it is secured to the lath. Plain tiles are laid on laths on mortar, with an overlap of 6 to 8 inches. At 6 inches gauge, it takes to cover a square of roofing 768 plain tiles; at 7 inches gauge, it takes 655 tiles; and at 8 inches gauge, 576 tiles. The average square of plain tiling is 700, and weighs 14 cwts. 2 qrs.

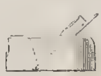
PLAN.—A draught or form; properly, anything drawn or represented on a plane, as a map or chart, but the word is usually applied to the horizontal geometrical section of anything, as a building, for example. The term is applied also to the draught or representation on paper of any projected work, as the *plan* of a house, of a city, of a harbour, &c.

PLANCEER, PLANCHER.—A ceiling, or the soffit of a cornice.

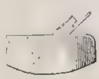
PLANE.—The plane is a cutting instrument on the guide principle. It is, in fact, a chisel guided by the stock or wooden handle in which it is set. The guide or sole of the stock is, in general, an exact counterpart of the form it is intended to produce. Planes are of various kinds, as the *jack*

Jack Plane

plane (about 17 inches long), used for taking off the roughest and most prominent parts of the stuff; the *trying plane*, which is used after the jack plane; the *long plane* (26 inches long), used when a piece of stuff is to be planed very straight; the *jointer*, still longer than the former, which is used for obtaining very straight edges; the *smoothing plane* ($7\frac{1}{2}$ inches long), and *block plane* (12 inches long), chiefly used for cleaning off finished work, and giving

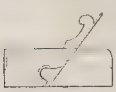


Smoothing Plane

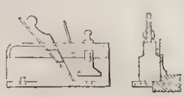


Compass Plane.

the utmost degree of smoothness to the surface of the wood; the *compass plane*, which is similar to the smoothing plane, but has its under surface convex, its use being to form a concave cylindrical surface. The foregoing are technically called *bench-planes*. There is also a species of planes called *rebate planes*, the first of which is simply called the *rebate plane*, being chiefly used for making rebates. Of the sinking rebating planes there are two sorts,

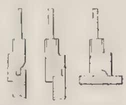


Rebate Plane



Fillister, side and end.

the *moving fillister* and the *sash fillister*, the first for sinking the edge of the stuff next the workman, and the second for sinking the opposite edge. The *plough* is a plane for sinking a channel or groove in a surface, not close to the edge of it. *Moulding planes* are for forming mouldings, and must vary according to the design. The *bead plane* is used for mouldings whose section is semicircular. Planes are also used for smoothing metal, and are wrought by machinery. See PLANING MACHINE.



Plough Moulding.

PLANE, THE ORIENTAL.—Description of properties and uses, p. 113.

PLANE, AMERICAN OR WESTERN. p. 113.

PLANE OF PROJECTION, PLANE OF DELINEATION, TRANSPARENT PLANE.—In perspective, the same as *plane of the picture*. See p. 228.

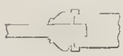
PLANING MACHINE.—A tool or instrument wrought by steam power, for saving manual labour in producing a perfectly plane surface upon wood or metal. This is usually accomplished, in metal-planing machines, by such an arrangement of mechanism, as will cause the object which is to be operated upon to traverse backwards and forwards upon a perfectly smooth and level bed, while the cutting tool is fixed to a cross slide above it, and slightly penetrates the surface as it is carried along. The tool is acted upon by screws, so as to enable the attendant to adjust the depth of the cut, and to move it with unerring precision over every part of the surface which it is required to plane. Planing machines for wood are described in the text, under LABOUR-SAVING MACHINES, p. 191–193.

PLANING MACHINE.—Furness' patent, p. 193.

PLANK.—A broad piece of sawed timber, differing from a board only in being thicker. Broad pieces of sawed timber which are not more than 1 inch, or $1\frac{1}{4}$ inch thick, are called *boards;* like pieces, from $1\frac{1}{2}$ to 3 or 4 inches thick, are called *planks*. Sometimes pieces more than 4 inches thick are called *planks*.

PLANS OF STAIRS.—The mode of setting out, p. 198.

PLANTED.—In joinery, a projecting member wrought on a separate piece of stuff, and afterwards fixed in its place, is said to be *planted;* as a *planted* moulding.



PLASTER.—A composition of lime, water, and sand, well mixed into a kind of paste, and used for coating walls and partitions of houses. This composition when dry becomes hard, but still retains the name of plaster. Plaster is sometimes made of different materials, as chalk, gypsum, &c., and is sometimes used to parget the whole surface of a building. Plaster is also the material of which ornaments are cast in architecture, and also that with which the fine stuff or gauge for mouldings and other parts is mixed, when quick setting is required.

PLAT, OR PLOT.—A word used by old authors for *plan*.

PLAT-BAND.—1. Any flat rectangular moulding, the projection of which is much less than its width; a fascia.—2. A lintel formed with voussoirs in the manner of an arch, but with the intrados horizontal.—3. The fillets between the flutes of the Ionic and Corinthian pillars.

PLATE.—A general name for all timber laid horizontally in a wall to receive the ends of other timbers, such as a *wall plate*.

PLATFORM.—A flat covering or roof of a building, suited for walking on; a terrace or open walk on the top of a building.

PLETHORA.—A disease of trees. See p. 97.

PLINTH.—A square member serving as the base of a column, the base of a pedestal, or of a wall. The square member, for instance, under the torus of the Tuscan base is the plinth. See woodcut, COLUMN.

PLOT.—A plan.

PLOT, *v.*—To make a plan of anything.

PLOTTING.—In surveying, the describing or laying down upon paper the several angles and lines of a tract of land which has been surveyed and measured. It is usually performed by means of a *protractor;* sometimes by the *plotting scale* (which see).

PLOTTING-SCALE.—A scale of equal parts, with its divisions along its edge, so that measurements may be made by application. A particular kind of plotting-scale is sometimes used in setting off the lengths of lines in surveying. It consists of two graduated ivory scales, one of which is perforated nearly its whole length by a dovetail-shaped slit, for the reception of a sliding-piece. The second scale is attached to this sliding-piece, and moves along with it, the edge of the second scale being always at right angles to the edge of the first. By this means the rectangular co-ordinates of a point are measured at once on the scales, or the position of the point laid down on the plan.

PLOUGH.—A joiner's grooving-plane. See PLANE.

PLUG CENTRE-BIT.—A modified form of the ordinary centre-bit, in which the centre-point or pin is enlarged into a stout cylindrical plug, which may exactly fill a hole previously bored, and guide the tool in the process of cutting out a cylindrical countersink around the same, as, for example, to receive the head of a screw-bolt.

PLUMB.—Perpendicular, that is, standing according to a plumb-line. The post of the house or the wall is said to be *plumb*.

PLUMB-LINE.—A line perpendicular to the plane of the horizon; or a line directed to the centre of gravity in the earth. See PLUMMET, PLUMB-RULE.

PLUMB-RULE.—A simple instrument for the same purpose as the plumb-line or plummet, used by masons, bricklayers, and carpenters. It consists of a board with parallel edges; a line is drawn down the middle of the board, and to the upper end of this line the end of a string is attached, carrying a piece of lead at its lower end. When the edge of the board is applied to a wall or other upright object, the exact coincidence of the plumb-line with the line marked on the board indicates that the wall or other object is vertical, while the deviation of the plumb-line from that on the board, shows how far the object is from the perpendicular. Sometimes another board is fixed across the lower end of the plumb-rule, having its lower edge at right angles to the line drawn on the other. In this case it becomes a level.

PLUMMET.—1. A long piece of lead attached to a line, used in sounding the depth of water.—2. An instrument used by carpenters, masons, &c., in adjusting erections to a perpendicular line. The terms *plummet*, *plumb-line*, and *plumb-rule* are often used synonymously. See PLUMB-LINE.

POCKET.—A hole in the pulley style of a sashed window. See p. 188.

POD-AUGER.—A name given in some localities to an auger formed with a straight channel or groove. See AUGER.

PODIUM.—In architecture, a continuous pedestal; a stylobate; also, a projection which surrounded the arena of the ancient amphitheatre, where sat persons of distinction.

POINTED, OR CHRISTIAN ARCHITECTURE. See GOTHIC.

POITRAIL, POITREL. See TIMBER HOUSES, p. 156.

POLE-PLATE.—A sort of smaller wall-plate laid on the top of the wall, and on the ends of the tie-beams of a roof, to receive the rafters.

POLINGS.—Boards used to line the inside of a tunnel during its construction, to prevent the falling of the earth or other loose material.

POLYCHROMY.—A modern term used to express the ancient practice of colouring statues, and the exteriors and interiors of buildings. This practice dates from the highest antiquity, but probably reached its greatest perfection in the twelfth and thirteenth centuries.

POLYFOIL.—An ornament formed by a moulding disposed in a number of segments of circles.

POLYGON.—To find the area of a regular polygon. Multiply half the perimeter by the perpendicular let fall from the centre upon one of the sides; or multiply the square of the side by the multiplier corresponding to the figure in the following table:—

Table of Polygons.

NAME.	No. of Sides.	Angle at Centre.	Perpendicular.	Multipliers.
Equilateral Triangle,	3	120°	0·2886751	0·4330127
Square, ...	4	90°	0·5000000	1·0000000
Pentagon, . . .	5	72°	0·6881910	1·7204774
Hexagon, .	6	60°	0·8660254	2·5980762
Heptagon,	7	$51\frac{3}{7}$°	1·0382607	3·6339124
Octagon, ...	8	45°	1·2071068	4·8284272
Nonagon, . . .	9	40°	1·3737387	6·1818242
Decagon, ...	10	36°	1·5388418	7·6942088
Undecagon, . . .	11	$32\frac{8}{11}$°	1·7028439	9·3656411
Dodecagon, . . .	12	30°	1·8660254	11·1961524

POLYGON.—To find the area of any regular polygon, Prob. LII. p. 15.

POLYGON OF FORCES, p. 120.

POLYGON, REGULAR.—About a given circle, to describe any regular polygon, Prob. XLVIII. p. 14.

POLYGON, REGULAR.—To describe a regular polygon with the same perimeter as another given polygon, but with twice the number of sides, Prob. XLIX. p. 14.

POLYGON, REGULAR.—To construct with the same perimeter as a given polygon, but with any different number of sides, Prob. L. p. 14.

POLYGON, REGULAR.—To describe with the same area as a given polygon, but a different number of sides, Prob. LI. p. 14.

POLYGON, REGULAR.—In a given circle, to inscribe any regular polygon, Prob. XLII. p. 12, Probs. XLIII.–XLVI. p. 13.

POLYGONS, REGULAR.—On a given straight line, to describe any of the regular polygons, Prob. XXXVII. Examples 1 and 2, p. 11.

POLYGONS, Line of, on the Sector.—Construction and use of, p. 38.

POLYSTYLE.—An edifice in which there are many columns.

POMEL, POMMEL.—A knob or ball used as a finial to the conical or dome shaped roof of a turret, pavilion, &c.

POPLAR, THE.—Description of the properties and uses of, p. 112.

POPPY HEAD.—An ornament carved on

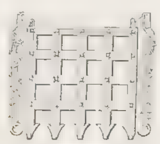
Poppy Head, Minster Church.

the raised ends of seats, benches, and pews in old churches.

PORCH.—An exterior appendage to a building, forming a covered approach or vestibule to a doorway. The porches in some of the older churches are of two stories, having an upper apartment, to which the name *parvise* is sometimes applied.

PORTAL.—1. The lesser gate when there are two of different dimensions at the entrance of a building.—2. A term formerly applied to a little square corner of a room, separated from the rest by a wainscot, and forming a short passage into a room. -3. A kind of arch over a door or gate, or the frame-work of the gate.

PORTCULLIS.—A strong grating of timber or iron, resembling a harrow, made to slide in vertical grooves in the jambs of the entrance gate of a fortified place, to protect the gate in case of assault. The vertical bars, when of wood, were pointed with iron at the bottom, for the purpose of striking into the ground when the grating was dropped, or of injuring whatever it might fall upon. In general



Portcullis.

there were a succession of portcullises in the same gateway. It is sometimes called a *portcluse*. The portcullis, with the chains by which it was moved attached to its upper angles, formed an armorial bearing of the house of Lancaster; and is of frequent occurrence as a sculptured ornament on buildings erected by the monarchs of the Lancaster family, as on Henry VII.'s Chapel and King's College Chapel, Cambridge. As an architectural device, it is usually surmounted by a crown, and placed alternately with a rose, also surmounted by a crown.

PORTICO.—An open space before the entrance of a building, fronted with columns. Porticoes are distinguished as prostyle or in antis, as they project before or recede within the building. They are further distinguished by the number of their columns; as a tetrastyle, hexastyle, and octastyle portico. See AMPHIPROSTYLE and ANTÆ.

POST.—A piece of timber set upright, and intended to support something else; as the *posts* of a house, the *posts* of a door, the *posts* of a gate, the *posts* of a fence. It also denotes any vertical piece of timber, whose office is to support or sustain in a vertical direction; as a *king-post, queen-post, truss-post, door post*, &c.—*Post and paling*, a close wooden fence, constructed with posts fixed in the ground and pales nailed between them.—*Post and railing*, a kind of open wooden fence for the protection of young quickset hedges, consisting of posts and rails, &c. These terms are sometimes confounded.

POST AND PANE, POST AND PAN, POST AND PETRAIL.—Another name for half-timbered houses, or those in which the walls are composed of timber framing, with panels of brick, stone, or lath and plaster. See p. 156, Plates XLVI. and XLVII.

POST AND PETRAIL. See POST AND PANE.

POSTERN.—Primarily, a back door or gate; a private entrance. Hence, any small door or gate.

POSTICUM.—The part of a temple at the rear of the cella or body. See PRONAOS.

POSTIQUE.—Superadded; done after the main work is finished. Applied to a superadded ornament of sculpture or architecture.

POYNTELL.—Paving set in squares or lozenge forms.

PRACTICAL CARPENTRY.—Introduction to, p. 134.

PRÆCINCTIONES.—The passages between the rows of seats in the Roman theatres, called also *balteæ* or *belts*.

PRESERVATION OF TIMBER BY SURFACE APPLICATIONS, as tar, pitch, tallow, paints, paint with sand, and sheathing with copper or copper nails, p. 108.

PRESERVATION OF WOOD BY IMPREGNATING IT WITH CHEMICAL SUBSTANCES. Kyan's process with corrosive sublimate, called *kyanizing*, p. 106; Margary's process, acetate or sulphate of copper, p. 106; Burnett's process, chloride of zinc, p. 106; Payne's process, two solutions, p. 106, 107; Bethell's process, creosote, p. 107; Boutigny's process, oil of schistus, p. 107; Boucherie's process with various chemical solutions, absorbed by aspiration, p. 107; mode of impregnating the wood with solutions for its preservation, p. 107, 108.

PRICK-POST.—The same as *queen post* (which see), p. 156.

PRICKER. p. 42.

PRICKING-UP.—In plastering, the first coats of plaster in three coat work upon lath.

PRINCIPALS, OR PRINCIPAL RAFTERS.—Those which are larger than the common rafters, and which are framed at their lower ends into the tie-beam, and at their upper ends are either united at the king-post, or made to bear against the ends of the straining-beams when queen posts are used. The principals support the purlins, which again carry the common rafters, and thus the whole weight of the roof is sustained by the principals. The struts, braces, &c., used in framing with the principal rafters, are sometimes called *principal struts, principal braces*, &c.

PRINT.—A plaster cast of a flat ornament, or an ornament of this kind formed of plaster from a mould.

PRISM.—A solid, of which the ends are equal, similar, and parallel rectilineals; and the other sides are parallelograms.—To find the surface of a prism. Rule: Find the area of one of its ends, and to its double add the sum of the areas of the parallelograms.—To find the solidity of a prism. Rule: Find the area of one of its ends, and multiply it by the length or perpendicular height.

PRISM, OR PYRAMID.—Development of a, p. 70.

PRISM.—Development of the covering of a prism, p. 71.

PRISMOID.—A body that approaches to the form of a prism; a solid having for its two ends any dissimilar parallel plane figures of the same number of sides, and its upright sides trapezoids.

PROFILE.—The outline or contour of anything, such as a building, a figure, a moulding.

PROJECTION, PROJECTURE.—The jutting out of certain parts of a building beyond the naked wall, or the jutting out of anything in advance of a normal line or surface.

PROJECTION.—Definition of projection, p. 46; general principles of projection, p. 47; planes of projection illustrated, p. 47.

PROJECTION.—Intersections of lines and planes under various conditions, p. 47–52.

PROJECTION OF SOLIDS. p. 52.

PROJECTIONS.—To find the projections of the intersections of two cylinders under various conditions, p. 63; to find the projections of the intersections of a sphere and cylinder, p. 64; to find the projections of the intersections of two right cones, p. 64.

PRONAOS.—The space in front of the naos or cella of a Greek temple. The term is sometimes used for *portico*. See NAOS.

PROPERTIES OF TIMBER.—Table of the, p. 133.

PROPORTION.—In architecture, the just magnitude of each part, and of each part compared with another in relation to the end or object in view.

PROPORTION of TREAD and RISER of a STEP, p. 196.

PROPORTIONAL COMPASSES.—Different kinds of, and their use, p. 33.

PROPYLÆUM, PROPYLON.—The porch, vestibule, or entrance of an edifice.

PROSCENIUM.—That part of a theatre from the curtain or drop-scene to the orchestra. In the ancient theatre it comprised the whole of the stage.

PROSTYLE.—A range of columns standing detached from the building to which they belong. See PORTICO.

PROTECTION OF WOOD AGAINST FIRE, p. 108; means adopted, p. 108; not efficacious, p. 109.

PROTRACTOR.—An instrument for laying down and measuring angles on paper. See p. 41.

PSEUDISIDOMON.—A manner of building among the Greeks, in which the height, length, and thickness of the courses differed.

PSEUDO-DIPTERAL.—Falsely or imperfectly dipteral, the inner range of columns being omitted. A term denoting a building or temple, wherein the distance from each side of the cella to the columns on the flanks is equal to two intercolumniations, the inner range of columns necessary to a dipteral edifice being omitted. As a noun, an imperfect peripteral, in which the columns at the wings were set within the walls. See PERIPTERAL.

PSEUDO-PERIPTERAL.—A term applied to a temple having the columns on its sides attached to the walls, instead of being arranged as in a peripteral.

PSEUDO-PROSTYLE.—A term suggested by Professor Hosking, to denote a portico, the projection of which from the wall is less than the width of its intercolumniation.

PTEROMA.—The space between the wall of the cella of a temple and the columns of the peristyle; called also *ambulatio*.

PUG PILES.—Piles mortised into each other by a dove-tail joint. They are also called *dove-tailed piles*.

PUG-PILING.—A mode of fixing piles by mortising them into each other by a dove-tail joint. Also termed *dove-tailed piling*.

PUGGING.—Any composition, generally a coarse kind of mortar, laid on the sound boarding under the boards of a floor, to prevent the transmission of sound. In Scotland it is termed *deafening*. See p. 151.

PULLEY-MORTISE.—The same as *chase-mortise* (which see).

PULLEY-STYLE.—The style of a window case, in which the pulleys are fixed. See p. 187.

PULPIT, PULPITUM.—An elevated place or inclosed stage in a church, in which the preacher stands. It is called also a *desk*. Pulpits in modern churches are of wood, but in ancient times some were made of stone, others of marble, and richly carved. Pulpits were also sometimes erected on the outside of churches as well as within.

PULPIT, with Acoustical Canopy.—Illustration and description of, Plate LXXXIII. p. 190.

PULVINATED.—A term used to express a swelling in any portion of an order, such for instance as that of the frieze in the modern Ionic order.

PUMP-BIT.—A species of large auger with removable shank, such as is commonly used for boring wooden pump barrels.

PUNCHEON.—A post (see Fig. 1, Plate XXXII., Roof of Westminster Hall, and description, p. 145); a small upright piece of timber in a partition, now called a *quarter*.

PURLIN.—A piece of timber laid horizontally, resting on the principals of a roof to support the common rafters. Purlins are in some places called *ribs*.

PURLINS.—To find the dimensions of, p. 137.

PUTLOGS.—Short pieces of timber used in scaffolds to carry the floor. They are placed at right angles to the wall, one end resting on the ledgers of the scaffold and the other in holes left in the wall, called *putlog-holes*. See LEDGER.

PUTTY.—1. A very fine cement made of lime only. The lime is mixed with water until it is of such consistence that it will just drop from the end of a stick. It is then run through a hair sieve, to remove the gross parts. Putty differs from *fine-*

stuff in the mode of its preparation, and in having no hair mixed with it.—2. A cement compounded of whiting and linseed oil, kneaded together to the consistence of dough, used for stopping small cavities in wood-work and for fixing the glass in window frames.

PYCNOSTYLE.—In ancient architecture, a building where the columns stand very close to each other. To this intercolumniation one diameter and a half is assigned.

PYRAMID.—A solid which has a rectilinear figure for its base, and for its sides triangles with a common vertex.—To find the surface of a pyramid. Rule: Find separately the area of the base and the areas of the triangles which constitute its sides, and add them; their sum will be the whole surface.—To find the solid content of a pyramid. Rule: Find the area of the base, and multiply it by the perpendicular height, and one-third of the product will be the solid content.

Q.

QUADRA.—A square frame or border inclosing a bas-relief, but sometimes used to signify any frame or border; the plinth of a podium.

QUADRÆ.—The fillets above and below the scotia of the Attic base.

QUADRANGLE.—A square surrounded with buildings, as a cloister or the buildings of a college.

QUADRILATERAL figure equal to a pentagon.—To describe, Prob. XXXVI. p. 11.

QUARREL.—A lozenge-shaped pane of glass used in leaded casements, or any pane of glass so used; also, the opening in which the glass is set; a small square or lozenge-shaped paving tile or stone.

QUARTER-GRAIN.—When timber is split in the direction of its annular plates or rings. When it is split across these, towards the centre, it is called the *felt-grain*.

QUARTER-ROUND.—The echinus moulding.

QUARTER-SPACE.—The name given to the resting-place or foot-pace of a stair, when it occurs at the angle turns of the stair. See p. 196.

QUARTERED PARTITION.—A partition formed with quarters. See Plate XLV. p. 155.

QUARTERING.—Forming partitions with quarters.

QUARTERS.—The vertical timber-framing of a partition to which the laths are nailed; called also *studs*, and in Scotland *standards*. See p. 156.

QUATREFOIL.—A piercing or panel formed by cusps or foliations into four leaves, or more correctly the leaf-shaped figure formed by the cusps. An ornament similar to the four leaves of a cruciform flower, frequently used as a decoration in hollow mouldings in the early English and Decorated styles, but which it has been proposed to distinguish by the term *quatrelobe*.

Quatrefoils

QUEEN-POST.—The suspending posts in the framed principal of a roof, or in a trussed partition, or other truss where there are two. See woodcut, under ROOF. When there is only one post, it is called a *king-post* or *crown-post*. See p. 136.

QUEENS.—In slating, slates measuring 3 feet by 2 feet.

QUERCUS ROBUR, p. 109; *Q. pedunculata*, p. 109; *Q. sessiliflora*, p. 109; *Q. ilex*, p. 109; *Q. suber*, p. 109; *Q. pyrenaica*, p. 109; *Q. cerris*, p. 110; *Q. virens*, p. 110; *Q. alba*, p. 110.

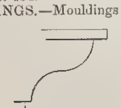
QUINDECAGON.—A plane figure with fifteen sides and fifteen angles.

QUIRK.—A deep indentation; the hollow under the abacus of a column.

QUIRK BEAD. p. 184.

QUIRK MOULDINGS.—Mouldings whose apparent projection is increased by the addition of a quicker curve.

Quirked Ogee



Plain Ogee.

QUIRKED OVOLO, The.—To describe, p. 179.

QUOIN.—The external angle of a building, and generally the stones of which that angle is formed. When the quoin stones project beyond the general surface of the wall, and have their arrises chamfered, they are called *rustic quoins*. Quoins are sometimes in Scotland called *external corners*.

R.

RABBET. See REBATE.

RAD AND DAB.—A substitute for brick-nogging in partitions, consisting of cob or a mixture of clay and chopped straw, filled in between laths of split oak or hazel; called also *wattle and dab*.

RADIUS OF A CIRCLE.—The span or chord and versed sine of a circle being given, to find the radius, Prob. LXI. p. 17.

RAFTERS.—Pieces of timber which form the framework of the slopes of a roof. Common rafters are those to which the slate boarding or lathing is attached. See ROOF.

RAFTERS.—To calculate the dimensions of, p. 137.

RAG-WORK.—A kind of rubble masonry, formed with stones about the thickness of a brick.

RAGLET, OR RAGLIN (corruption of *regula*).—A rectangular groove cut in stone or brick work.

RAGLINS.—A term used in the north of England for the slender ceiling-joists of a building.

RAILS.—The horizontal timbers in any piece of framing. See FRAMING and DOOR, and also p. 186.

RAISED PANELS. p. 185.

RAISING PLATE, RESON PLATE.—The wall-plate; or more generally, any horizontal timber which, laid on walls or borne by posts or puncheons, sustains other timbers. See p. 156.

RAKE.—A slope or inclination.

RAKER.—An iron tool used by bricklayers to rake out decayed mortar from the joints of brick-work, preparatory to repointing them.

RAKING COURSES.—Diagonal courses of brick, laid in the heart of a thick wall, between the outside courses.

RAKING MOULDINGS.—Those which are inclined from the horizontal line, as in the sides of a pediment.

RAKING MOULDINGS.—To describe, p. 181.

RAMP.—Literally, a spring or bound; any sudden rising interrupting the continuity of a sloping line; a concave sweep connecting a higher and lower part of some work, as the coping of a wall, or the higher and lower parts of a stair-railing at a half or quarter pace; a flight of steps, or the line tangential to the steps.

RAMP AND TWIST.—A line which rises and winds at the same time, as the section of a vertical cylinder by an inclined plane.

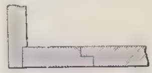
RAMPANT ARCH.—One whose imposts are not of the same height. See RAMPANT ELLIPSES, Figs. 167, 169, p. 24, 25.

RANCE.—A shore or prop. [Scotch.]

RAND.—A border or margin, or a fillet cut from a border or margin in the process of straightening it.

RANDOM TOOLING.—In Scotland called *droving*, is a mode of hewing the face of a stone, either as preparatory to some other process, or as a finishing operation. The chisel used is from 2 to 4 inches broad, and is called variously a *broad tool*, a *tooler*, or a *drove*. Having ground it to a fine and even cutting edge, the workman holding it in his left hand with its edge upon the stone, strikes its head with a wooden mallet, so as to advance it about $\frac{1}{8}$ inch, producing a cut or indentation of that length, and of the whole width of the tool. By successive strokes the tool is advanced to the extremity of the stone, and the result is a series of indentations or flutings at right angles to its path, or to the draught, as it is termed. The same operation is repeated till the whole surface of the stone is worked over. The excellence of the work depends on the regularity of the minute flutings, and the absence of ridges between the draughts.

REBATE.—A rectangular longitudinal recess made in the edge of any substance. Thus the rectangular recess made in a door-frame, into which the door shuts, is a *rebate*.—*Rebate joint*, in joinery, a joint formed by making rebates or longitudinal recesses in the opposite edges of the boards to be joined. See p. 182, 183.



Rebate Joints

REBATE.—A kind of hard freestone used in pavements; also, a piece of wood fastened to a long stick, for beating mortar.

REBATE (more commonly spelled *rybat*).—The rebated reveal of a door or window. See illustration, OUT AND IN BOND.

REBATE PLANES.—Planes used in forming and finishing rebates in joiner-work; or, as it is technically termed, sinking rebates. Of these there are the moving fillister, used, in sinking rebates, on the edge of the board next to the workman, and the sash fillister in sinking the rebate on the edge furthest from him; and the guillaumes, skewed and square, the former for finishing the rebate across the direction of the fibre, and the latter for finishing it in the direction of the fibre.

RECESS.—A small cavity or niche formed in the wall of a building. Exhedræ, tribunes, alcoves come under this denomination, and afford considerable additional space. They add to the commodiousness of dining-rooms, drawing-rooms, libraries, &c.

RECESSED ARCH.—One arch within another. Such arches are sometimes called double, triple, &c., and sometimes compound arches.

RECTANGLE.—To construct a rectangle equal to a given triangle, Prob. XXIII. p. 9.—To construct a rectangle whose sides shall be equal to two given lines, Prob. XXV. p. 9.—To describe a rectangle or parallelogram having one of its sides equal to a given line, and its area equal to a given rectangle, Prob. XXVII. p. 10.—To construct a rectangle upon a given line, and equal to a given square, Prob. XXVIII. p. 10.—To describe a rectangle equal to a given rhomboid, Prob. XXXIV. p. 11.—To describe a rectangle equal to a given irregular quadrilateral figure, Prob. XXXV. p. 11.—To describe a rectangle equal to a given circle, Prob. LXXIV. p. 20.

RECTILINEAR FIGURE.—To describe any figure equal and similar to a given rectilinear figure, Prob. LIII. p. 15.—To describe, on a given line, a figure similar to a given rectilinear figure, Prob. LIV. p. 15.

RED OR YELLOW PINE. p. 116.

RED OR YELLOW PINE.—Causes to which the rapid decay of home-grown timber may be attributed. See p. 117.

RED OR YELLOW PINE.—Characteristics of Memel, Norway, and Swedish timber. See p. 117.

REEDS.—A moulding consisting of several beads side by side.

REGLET, REGULA.—A small moulding, rectangular in its section; a fillet or listel. Also, a rectangular groove.

REGRATING.—Rehewing or otherwise renewing the surface of a hewn stone.

REGULAR BODIES.—Those which have all their sides, faces, and angles similar and equal. They are only five in number—namely, the tetrahedron, hexædron, octahedron, dodecahedron, and icosahedron. These are also called the *Platonic bodies*.—To find the surface of any of the regular bodies. Rule: Multiply the square of its linear side by the proper number in the annexed table under "surface;" and to find the solid content, multiply the cube of its linear side by the proper number under "solidity."

No. of Faces	NAMES.	Surface when the Side is 1.	Solidity when the Side is 1.
4	Tetrahedron . . .	1·7320508	0·1178511
6	Hexædron . .	6·0000000	1·0000000
8	Octahedron . .	3·4641016	0·4714045
12	Dodecahedron .	20·6457788	7·6631189
20	Icosahedron . . .	8·6602540	2·1816950

REGULAR FIGURES.—Those whose sides and angles are equal, as the square and equilateral triangle, pentagon, hexagon, &c. Circles can be inscribed within and about all the regular figures, and the area of any of them may be found by the particular rule given under the proper word, or by this general rule: Multiply half the perimeter of the figure by the perpendicular let fall from the circumscribed or inscribed circle, on any of its sides.

REGULAR POLYHEDRONS, The.—Description of, p. 69.

REGULAR POLYHEDRONS, The.—Development of, p. 70.

REINS OF A VAULT.—The sides or walls which sustain it.

RELIEF, Rilievo. The projecture or prominence of a figure above or beyond the ground or plane on which it is formed. Relief is of three kinds: high relief (*alto rilievo*), low relief (*basso*

High Relief

rilievo), and half relief (*mezzo rilievo*). The difference is in the degree of projection. *High relief* is formed from nature, as when a figure projects as

Low Relief.

much as the life. *Low relief* is when the figure projects but little, as in medals, festoons, foliages, and other ornaments. *Half relief* is when one-half of the figure rises from the plane.

REMOVING CENTRES, or Striking Centres, p. 175

RENAISSANCE.—A term applied to the style of building and decoration which came into vogue in the early part of the sixteenth century, professedly a return to the classic architecture of Greece and Rome. It was, nevertheless, a tasteless adherence to the dogmas and rules of Vitruvius, in which everything was to be designed by rule and line, and nothing left to the invention of the architect. Chateaubriand characterizes the French examples of the Renaissance as "bastard Roman, cold and servile, neither in harmony with the climate, nor suited to the wants of the people."

RENDER.—To plaster on walls, slates, or tiles, directly and without the intervention of laths.

RENDER and Set. -Two-coat plaster on walls.

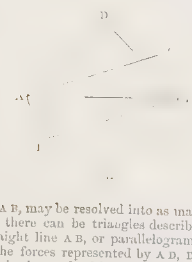
RENDER, Float, and Set.—Three coat plaster on walls.

REREDOS, Rerdos, Reredosse. -The back of a fire-place; an altar-piece; a screen or partition wall separating the chancel from the body of a church.

RESINOUS WOODS.—General description of, p. 115.

RESISTANCE of Timber.—To tension, p. 124. —To compression, p. 124 -To transverse strain, p. 126.—To torsion, p. 124.

RESOLUTION and Composition of Forces. —The term *resolution of forces or of motion*, in dynamics, signifies the dividing of any single force or motion into two or more others, which, acting in different directions, shall produce the same effect as the given motion or force. This is the reverse of *composition of forces or of motion*. Thus let A B, in the annexed diagram, represent the quantity and direction of some given force; draw any lines A C, A D; and join C B, D B, and complete the parallelograms A D B E, A C B F. Then by composition of forces the force A B is equivalent to A D and A E, or to A C and A F. Hence it is evident that a given



force, as A B, may be resolved into as many pairs of forces as there can be triangles described upon a given straight line A B, or parallelograms about it. And as the forces represented by A D, D B, or A C, C B, may also be resolved into other pairs of forces, it appears that by proceeding in the same manner with the successive pairs of forces, a given force may be resolved into an unlimited number of others, acting in all possible directions. See p. 120.

RESPOND. -A pilaster or half pillar responding to another similar, or to a whole pillar opposite to it.

RESTING PLACE.—A half or quarter pace in a stair.

RESTING POINTS.—In handrailing, the heights set up to obtain the section of a cylinder in forming the wreath. See p. 202.

RESULTANT.—In dynamics, the force which *results* from the *composition* of two or more forces acting upon a body. When the two forces act upon a body in the same line of direction, the resultant is equivalent to the sum of both; when they act in opposite directions, the resultant is equal to their difference, and acts in the direction of the greater. If the lines of direction of the two forces are inclined to each other, then on taking in each direction, from the point where they intersect, a straight line to represent each of the forces respectively, and constructing a parallelogram of which these lines are the adjacent sides, the resultant is represented in intensity and direction by the diagonal of the parallelogram passing through the point of intersection. By combining this resultant with a third force, a new resultant will be obtained; and in this manner the resultant of any number of forces may be determined. See p. 120.

RETICULATED MOULDING.—In architecture, a member composed of a fillet interlaced in various ways like network. It is seen chiefly in buildings in the Norman style.

RETICULATED WORK.—In architecture, that wherein the stones are square and laid lozenge-

Reticulated Work.

wise, resembling the meshes of a net. This species of masonry was very common among the ancients.

RETURN.—A disease of trees. See p. 97.

RETURN, in building, denotes a side or part that falls away from the front of any straight work.

RETURN BEAD.—One which shows the same appearance on the face and edge of a piece of stuff, forming a double quirk.

REVEALS, or Revels.—The sides of an opening for a door or window, between the framework and the face of the wall. In Scotland termed frequently *rybat-head*, or, probably from the way in which it is cut *rebate-head*. See woodcut, under Back-Fillet.

RIBBING.—An assemblage of ribs.

RIBS, in carpentry and joinery, are curved pieces of timber to which the laths are fastened, in forming domes, vaults, niches, &c. In architecture, projecting bands or mouldings used in ornamented ceilings, both flat and curved, but more commonly in the latter, especially when groined.

RIDGE.—The highest part of the roof of a building. But in architecture the term is more particularly applied to the meeting of the upper end of the rafters. When the upper end of the rafters abut against a horizontal piece of timber, it is called a *ridge piece* or *ridge-plate*. Ridge is also used to signify the internal angle or nook of a vault. *Ridge-tile*, a convex tile made for covering the ridge of a roof.

RIDGE-PIECE, Ridge-Plate.—A piece of timber at the ridge of a roof, against which the common rafters abut. Called also *pole-plate*.

RIDGE-ROLL, or Ridge-Batten.—A rounded piece of timber, over which the lead is turned in the ridges and hips of a roof. It is generally about 2 inches diameter, and fixed to the ridge of the roof by spikes about 4 feet apart.

RIGA TIMBER. Pinus sylvestris, p. 116.

RILIEVO. See Relief.

RING-COURSE.—The outer course of stone or brick in an arch.

RIPPING SAW.—One used for cutting wood in the direction of the fibres.

RISERS OF STEPS. p. 196.

RISING HINGE.—One so constructed as to raise the door to which it is attached, as it opens.

ROCK-WORK, or Rocking, in masonry, as its name implies, is that mode in which the stone has an artificial roughness given to it to imitate the natural face of a rock. It is thus performed: Rough draughts are cut round the face of the stone, from which the beds and joints are squared up. The workman then, with a pitching tool and mallet, or with a hammer similar to a nidging hammer, breaks or splits away pieces from the face and arrises of the stone, striving to avoid the appearance of formality, and taking care not to leave tool marks. It is an especial object, in taking out the pieces from the edges, that those in the two contiguous stones shall correspond as nearly as may be in size and depth, so that the whole surface of the wall, when completed, may look as inartificial as possible. It is only in dressing such stones as admit of a piece being struck out of their face by a blow, without leaving a hammer mark, that rock-work is admissible. Rock-work, formed by the chisel and mallet, is insipid in the extreme, and its use evinces bad taste, as well as a lack of judgment.

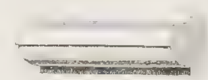
ROCOCO.—A debased variety of the Louis-Quatorze style of ornament, proceeding from it through the degeneracy of the Louis-Quinze. It is

Rococo Ornament.

generally a meaningless assemblage of scrolls and crimped conventional shell work, wrought into all sorts of irregular and indescribable forms, without individuality and without expression. This term is sometimes applied in contempt to anything bad or tasteless in ornamental decoration.

ROD.—A measure of length equal to $16\frac{1}{2}$ feet. A square rod is the usual measure of brick-work, and is equal to $272\frac{1}{4}$ square feet.

ROLL-MOULDING.—A round moulding divided longitudinally along the middle, the upper half of which projects over the lower. It occurs often in the later period of the Early English and



Roll Moulding.

in the Decorated style, where it is profusely used for drip-stones, string courses, abacuses, &c. -*Roll and fillet moulding*, a round moulding with a square

Roll and Fillet Moulding.

fillet on the face of it. It is most usual in the early Decorated style, and appears to have passed by various gradations into the ogee.

ROMAN ARCHITECTURE.—The style of architecture used by the Romans. Founded on the Grecian architecture, the Roman is, though less chaste and simple, more varied, richer, and in some respects bolder and more imposing. It embraces two additional orders of columns, the Tuscan and the Composite. All its curved mouldings are more circular and have greater projection, and its pediments are steeper. Ornaments, too, are more frequently introduced. It is further characterized by the use of the arch, which in its late periods was one of its leading features, and was unknown in the architecture of the Greeks.

ROMANESQUE.—A general term for all those styles of architecture which, commencing with the Christian era, sprung from the Roman, and flourished in Europe till the introduction of Gothic architecture. In all these there is an evident imitation of the features of classical Roman architecture, altered and debased. There is still a prevalence of horizontal lines, of rectangular faces, and square-edged projections, and of arches supported on pillars retaining traces of classical proportions. The openings in the walls are small, and subordinate to the surfaces in which they occur; the members of the architecture massive and heavy. The styles are

known in their various modifications by the names of Byzantine, Lombard, Saxon, &c.

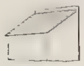
ROOD.—A measure equal to 36 square yards, by which rubble masonry is valued in Scotland. Rubble walls at and below 18 inches thick are reduced to 1 foot, and above 18 inches thick to 2 feet.

ROOD.—A measure of land, the fourth part of an acre, and equal to 40 square poles or 1210 square yards.

ROOD.—A cross, crucifix, or figure of Christ on the cross, placed in a church. The *holy rood* was a cross with an effigy of our Saviour, generally as large as life, elevated at the junction of the nave and choir, and facing the western entrance to the church. Sometimes images of the Virgin Mary and St. John were placed, the one on the one side, and the other on the other side, of the image of Christ.

ROOD-LOFT, Rood-Tower.—The gallery in a church where the *rood* and its appendages were placed. This loft or gallery was commonly placed over the chancel-screen in parish churches, or between the nave and chancel; but in cathedral churches it was placed in other situations. The *rood tower* or *steeple* was that which stood over the intersection of the nave with the transepts.

ROOF.—The cover of a building, irrespective of the materials of which it is composed. Roofs are distinguished: 1st. By the materials of which they are formed, as stone, brick, wood, slate roofs, &c. 2d. By their form and mode of construction, of which there is great variety, as shed, curb, hip, gable, pavilion, and ogee roofs. 3d. They are fur-


Shed Roof


Gable Roof


Hip Roof

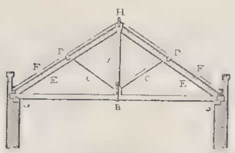

Conical Roof


Ogee Roof

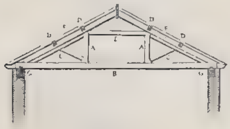

Curb Roof


M Roof

ther divided into *high-pitched* or *low-pitched* roofs, as their inclined sides make a greater or lesser angle with the horizon. In carpentry, roof signifies the timber frame-work by which the roofing or covering materials of the building are supported. This consists in general of the principal rafters, the pur-


King-post Roof

A, King post. B, Tie-beam. C C, Struts or braces. D D, Purlins. E E, Backs or principal rafters. F F, Common rafters. G G, Wall-plates. H, Ridge piece.


Queen post Roof

A A, Queen posts. B, Tie-beam. C C, Struts or braces. D D, Purlins. E, Straining beam. F F, Common rafters. G G, Wall-plates. H, Ridge piece.

lins, and the common rafters. The principal rafters, or principals, as they are more commonly termed, are set across the building at about 10 or 12 feet apart; the purlins lie horizontally upon these, and sustain the common rafters, which carry the covering of the roof. The preceding figures show the two varieties of principals which are in common use; the first, the king-post principal, and the second, the queen-post principal, with the purlins and common rafters *in situ*. The mode of framing here exhibited is termed a truss. Sometimes, when the width of the building is not great, common rafters are used alone to support the roof. They are in that case joined together in pairs, nailed where they meet at top, and connected with a *tie* at the bottom. They are then termed *couples* or *couple close*. See p. 85. In Asia, the roofs of houses are flat or horizontal. The same name, *roof*, is given to the sloping covers of huts and cabins, to the arches of oven-furnaces, &c.

ROOF COVERING.—Weight of the various kinds of, p. 137.

ROOFS.—Various forms of, as arising from variety in the forms of buildings, p. 85–91.

ROOFS.—Practical memoranda of construction in designing, p. 137.

ROOFS.—Classified according to their forms and the combination of their surfaces, p. 134.

ROOFS.—Slope of, according to various authors, p. 134; as settled by climate, p. 134; by M. Rondelet considered arbitrary, p. 134; as settled by material used as the covering, p. 134; Colonel Emy's remarks on, p. 134; Professor Robison's remarks on, p. 135.

ROOFS.—Examples of constructions of, p. 135.

ROOFS.—Illustration of the principles of trussing of, p. 136.

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ROOFS.—Mr. Tredgold's rules for the dimensions of the timbers in, p. 137.

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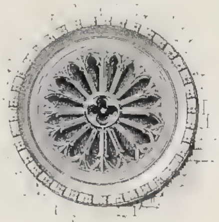
ROOT of a Tenon. p. 147.

ROSE-WINDOW.—A circular window divided into compartments by mullions or tracery radi-


Rose-window, St. David's

ating or branching from a centre. It is called also *Catherine wheel* and *Mary-gold window*.

ROSTRUM.—A scaffold or elevated place, where orations or pleadings are delivered; a pulpit.

ROTTENNESS in Trees. p. 97.

ROTUNDA.—A round building; any building that is round both on the outside and inside. The most celebrated edifice of this kind is the Pantheon at Rome.

ROUGH-BRACKETS. p. 196.

ROUGH-CAST, or Rough-Casting.—A covering for an external wall, composed of an almost fluid mixture of clean gravel and lime, which is dashed on the wall previously prepared for its reception by a coating of soft plaster, to which the rough-cast adheres.

ROUGH-HEW.—To hew coarsely without smoothing, as to *rough-hew* timber.

ROUGH-SETTER.—A mason who builds rough walling, as distinguished from one who hews also.

ROUGH-STRINGS. p. 196.

ROUTTER-GAUGE.—A gauge used for cutting out the narrow channels intended to receive brass or coloured woods in inlaid work. It is formed like the common marking gauge, but provided with a narrow chisel as a cutter, in place of the marking point.

ROUTTER-PLANE.—A kind of plane used for working out the bottoms of rectangular cavities. The sole of the plane is broad, and carries a narrow cutter, which projects from it as far as the intended depth of the cavity. This plane is vulgarly called the *old woman's tooth*.

RUBBING, or Polishing.—In stone cutting, after a stone is dressed by boasting or scabbling, the tool marks are, by the agency of a piece of Yorkshire stone or grit-stone as a rubber, used first with sand and water and then with water alone, obliterated, and a smooth polished surface is given to the stone. This is of all modes the best for finishing the surface of stone which is exposed to the weather, as the pores are completely filled and the surface does not retain moisture.

RUBBLE.—Stones of irregular shapes and dimensions.

RUBBLE-WORK, or Rubble-Walling.—Walls built of rubble stones. Rubble walls are either coursed or uncoursed; in the former, the stones are roughly dressed and laid in courses, but without regard to equality in the height of the courses; in the latter, the stones are used as they occur, the interstices between the larger stones being filled in with smaller pieces. When this is done with great nicety, and so as to preserve perfectly the horizontal and vertical bond by the complete interlacing of the amorphous stones, the operation is termed *snecking*, and the work is called *snecked rubble*.

RUDENTURE.—The figure of a rope or staff, plain or carved, with which the flutings of columns are sometimes filled. See Cabling.

RULES for calculating the dimensions of timbers exposed to different strains:—

1. To find the tenacity of a piece of timber, p. 124.

2. To find the diameter of a post that will sustain a given weight, when the length exceeds ten times the diameter, p. 125.

3. To find the scantling of a rectangular post to support a given weight, p. 125.

4. To find the dimensions of a square post that will sustain a given weight, p. 125.

5. To find the stiffest rectangular post that will support a given weight, p. 125.

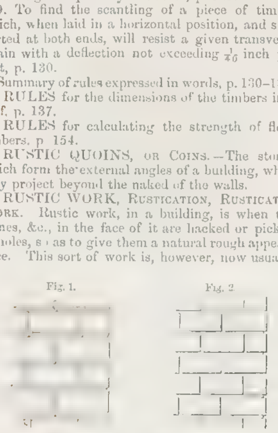
6. To find the strength of a rectangular beam fixed at one end and loaded at the other, p. 127.

7. To find the length of a rectangular beam, when it is supported at both ends and loaded at the middle, p. 127.

RUSTIC QUOINS, or Coins.—The stones which form the external angles of a building, when they project beyond the naked of the walls.

RUSTIC WORK, Rustication, Rusticated Work. Rustic work, in a building, is when the stones, &c., in the face of it are hacked or picked in holes, so as to give them a natural rough appearance. This sort of work is, however, now usually

Fig. 1. Fig. 2



Rustic Work.

Fig. 1 With chamfered joints. Fig. 2. With rectangular joints.

called *rock-work*, and the term *rustic* is applied to masonry worked with grooves between the courses, to look like open joints, of which there are several varieties. The same term is applied to walls built of stones of different sizes and shapes.

RUSTICATED ROCK-WORK.—In masonry, this term is sometimes applied to a kind of work in which the faces of the stones are left rough, the joints being chiselled either plain or chamfered. It is more correctly termed *rough-faced rustic*. It is applied in walls where a character of rude strength has to be expressed, as in bridges, retaining walls, and similar works.

S.

SABICU WOOD.—Properties and uses of, p. 115.

SACELLUM.—In ancient Roman architecture, a small inclosed space without a roof, consecrated to some deity. In mediæval architecture, the term signifies a monumental chapel within a church; also, a small chapel in a village.

SACOME.—In architecture, the exact profile of a member or moulding.

SACRARIUM.—A sort of family chapel in the houses of the Romans, devoted to some particular divinity.

SACRISTY, or Sacristry.—An apartment in a church where the sacred utensils are kept, and the vestments in which the clergyman officiates are deposited; now called the *vestry*.

SADDLE-BACKED COPING.—A coping thicker in the middle than at the edges; sloping both ways from the middle.

SAFETY-ARCH.—An arch formed in the substance of a wall, to relieve the part below it from the superincumbent weight. A discharging arch (which see)

SAFETY-LINTEL.—A name given to the wooden lintel which is placed behind a stone lintel, in the aperture of a door or window.

SAG.—To bend from a horizontal position.

SAIL OVER, *v.*—To project.

SAILING OVER.—In architecture, the name given by workmen to anything projecting beyond the naked of a wall, of a column, &c.

SALIENT, Saliant.—In architecture, a term used in respect of any projecting part or member.

SALLY.—In architecture, a projection; also, the end of a piece of timber cut with an interior angle formed by two planes across the fibres, as the feet of common rafters; called in Scotland a *face*.

SALOON.—A lofty, spacious hall, frequently vaulted at the top, and usually comprehending two stories, with two ranges of windows. A magnificent room in the middle of a building, or at the head of a gallery, &c. A state-room much used in palaces in Italy, for the reception of ambassadors and other visitors.

SAP-WOOD.—The external part of the wood of exogens, which from being the latest formed, is not filled up with solid matter. It is that through which the ascending fluids of plants move most freely. For all building purposes the sap wood is or ought to be removed from timber, as it soon decays.

SARACENIC ARCHITECTURE.—The name given to the architecture employed by the Saracens, who established their dominion over the greater part of the East in the seventh and eighth centuries. It may with equal propriety be styled Moslem or Mahometan architecture, from its originating in and diffusing itself over the world with the religion of Mahomet, and also from its being almost exclusively confined to nations professing that belief. The Saracens proper, or Arabians, do not appear to have possessed any native architecture of their own, but adopted and modified the existing styles as they found them among the states which submitted to their sway. Various styles, therefore, such as the Indian, Persian, and Egyptian varieties, arose in different countries, but may all be classed under the general head of Saracenic architecture. In process of time these gradually merged into each other, and a distinct style was formed, which, however, it is impossible minutely to characterize, owing to the numerous local circumstances by which it is modified. Its more prominent and familiar features are the bulb-shaped dome, borrowed originally from the Byzantine school, but assuming its peculiar shape under the hands of Moslem architects, and the lofty, slender turrets, known by the name of minarets, which are generally attached to the edifices of Mahometan worship. Those last are said to have been first erected by the Caliph Walid in the commencement of the eighth century. One branch, nevertheless, of Saracenic architecture, the Moorish, presents so many distinct features as to form a school of its own, and be regarded to a great extent as a type of the Mahometan style. It is admirably exemplified in the architectural remains in Spain of the Moors or African Saracens, who subdued that country in

[illegible]

the early part of the eighth century, and after long retaining their dominion over the greater part of it, were only finally driven from their last hold at Granada in 1492. The distinguishing characteristic of Moorish architecture, is the profusion of ornament with which the interior walls of buildings are overlaid. These ornaments are composed of mosaic work, richly interspersed with gilding, and give a most beautiful and fairy-like appearance to the apartments. The ceilings are decorated in the same manner with stucco-work, sometimes in honeycomb or stalactite patterns, richly gilded and painted in the most brilliant colours. In accordance with a precept of the Koran, which prohibits all representation of human or animal forms, no sculptured or painted figures, or similar imitations of animated nature, are to be met with; but the decorations in the best examples consist of a multiplicity of lines and curves, forming geometrical figures and an elegant variety of conventional foliage, all interlacing each other with the richest and most luxuriant effect. Almost every variety of arch is found in this style, but the horse shoe arch prevails, and the columns supporting it are often remarkable for their extreme slenderness and height. The exterior of Moorish buildings is comparatively plain, but the doorways and arches surmounting them are frequently, as shown in the annexed woodcut, adorned with the most exquisite and elaborate tracery. About the finest specimens of Moorish architecture in existence are the mosque at Cordova, now transformed into a cathedral, and the celebrated palace of the Alhambra at Granada.

SARCOPHAGUS.—1. According to Pliny, a species of stone used among the Greeks for making coffins, which was so called because it consumed the flesh of bodies deposited in it within a few weeks. It is otherwise called *lapis Assius*, and said to be found at Assos, a city of Lycia. Hence, -2. A stone coffin or stone grave, in which the ancients deposited bodies which they chose not to burn. Sarcophagi were made either of stone, of marble,

[illegible]

or of porphyry. Among the Greeks the form was generally oblong, the angles sometimes rounded, the exterior being richly sculptured with figures in relief. The lid or roof varies both in shape and ornamentation. The Egyptian sarcophagi are sculptured with hieroglyphics. One of the most celebrated is the great sarcophagus taken by the British in Egypt in 1801, commonly called that of Alexander. It is deposited in the British Museum.

SARKING.—The Scotch term for *slateboarding*.

SASH. The framed part of a window in which the glass is fixed.

SASH-FASTENER.—A latch or screw for fastening the sash of a window.

SASH-FRAME.—The frame in which the sash is suspended, or to which it is hinged. When the sash is suspended, the frame is made hollow to contain the balancing weights, and is said to be *cased*.

SASH-LINE.—The rope by which a sash is suspended in its frame.

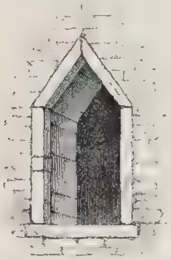
SASH-SAW.—A small saw used in cutting the tenons of sashes. Its plate is about 11 inches long, and has about 13 teeth to the inch

SAUL TREE, or Sal-Tree.—The name given in India to a tree of the genus Shorea, the *S. robusta*, which yields a balsamic resin, used in the temples under the name of *ral* or *dhoona*. The timber called *sal*, the best and most extensively used in India, is produced by this tree.

SAW.—A cutting instrument consisting of a blade or thin plate of iron or steel, with one edge dentated or toothed. The saw is employed to cut wood, stone, ivory, and other solid substances. The best saws are of tempered steel, ground bright and smooth. They are of various forms and sizes, according to the purposes to which they are to be applied. Those used by carpenters and other artificers in wood are the most numerous. Among these are the following:—The *cross-cut saw*, for cutting logs transversely, and wrought by two persons, one at each end. The *pit saw*, a long blade of steel with large teeth, and a transverse handle at each end; it is used in saw-pits for sawing logs into planks or scantlings, and is wrought by two persons. The *frame saw*, consisting of a blade from 5 to 7 feet long, stretched tightly in a frame of wood. It is used in a similar manner to the pit saw. The *ripping saw*, *half-ripper*, *hand-saw*, and *panel saw* are saws for the use of one person, the blades tapering in length from the handle. *Tenon saws*, *sash saws*, *dovetail saws*, &c., are saws made of very thin blades of steel, stiffened with stout pieces of brass, iron, or steel fixed on their back edges. They are used for forming the shoulders of tenons, dovetail joints, &c., and for many other purposes for which a neat, clean cut is required. *Compass* and *key-hole saws* are long narrow saws, tapering from about 1 inch to $\frac{1}{4}$ inch in width, and used for making curved cuts. The key-hole saw is inserted in a long hollow handle called a *pad*, and by a screw it is fixed in any required place, so that it may be made to project more or less, as required. Small *frame-saws* and *bow-saws*, in which very thin,

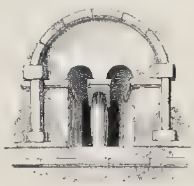
narrow blades are tightly stretched, are occasionally used for cutting both wood and metal. There are also *circular saws* and *band-saws*. Saws for cutting stone are without teeth.

SAXON ARCHITECTURE.—The architecture which prevailed in England previous to the Norman Conquest. Much dispute has taken place in regard to the existing specimens of building alleged to belong to the Anglo-Saxon period, it being maintained by various parties, that all traces of this style have now disappeared. A considerable degree of plausibility is given to this assertion, by the circumstance that many of the Saxon edifices were entirely, or nearly so, constructed of timber. It is indeed certain, that no entire Anglo Saxon building exists at the present day, but that portions of some ancient churches, such as towers, windows, and doorways, belong to the period preceding the Conquest, seems to be satisfactorily ascertained.



Window, Barnack Church, Northamptonshire.

It is difficult, if not impossible, to give an accurate description of its leading characteristics, but there can be little doubt of its being generally marked by extreme rudeness and simplicity, a circumstance which renders its disappearance, except to the antiquary and historian, a matter of comparatively small regret. The heads of windows and doors in Saxon architecture are triangular or semicircular,



Baluster Window, Monkwearmouth Church, Durham.

the former having apparently been copied from the debased Roman form to be seen on sarcophagi in the Roman catacombs. The semicircular arch is the most frequent, the earliest of which were constructed of large tiles, probably borrowed from the debris of Roman edifices. These tiles were placed on end, and the spaces between, which are nearly

Doorway of the Tower of Earls-Barton Church.

equal in width, filled in with rubble-work; the jambs or imposts of the arches were generally of stone as well as the walls, in which were sometimes laid courses of tile, either in horizontal layers, or in the diagonal manner called *herring-bone*, being evidently an imitation of the Roman structures in Britain. The Saxon mouldings were few and simple, consisting of a square-faced projection, with a chamfer or splay on the upper or lower edge. A peculiar feature in the Anglo-Saxon bell towers is to be remarked in the rude columns which divide the openings of the windows, and form a kind of baluster. These are seen in the towers of Monkwearmouth, Jarrow, Earls-Barton, and other churches; the tower of Earls-Barton combining in itself more of the characteristics of the Saxon style than any other known specimen.

SCABBLE.—In masonry, to dress a stone with a broad chisel, called, in England, a *boaster*, and in Scotland a *drove*, after it has been pointed or broached, and preparatory to finer dressing.

SCAGLIOLA.—In architecture, a composition, sometimes also called *mischia*, from the mixture of colours in it being made to imitate marble. It is composed of gypsum or sulphate of lime calcined and reduced to a fine powder, of which, with the addition of a solution of glue or isinglass, a fine paste is made, in which the requisite colours are diffused. It is used like stucco, and when fit for the operation, it is smoothed with pumice stone, and polished with tripoli, charcoal, and oil. Columns are formed of it, as those of the Pantheon in London.

SCALES FOR DRAWING. p. 35.

SCAMILLUS, SCAMILLI.—In ancient architecture, a sort of second plinths or blocks under statues, columns, &c., to raise them, but not, like pedestals, ornamented with any kind of moulding.

s, Scamillus.

SCANTLE.—Among slaters, a gauge by which slates are regulated to their proper length.

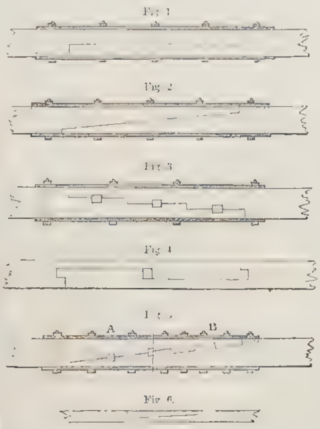
SCANTLING.—1. In carpentry, the dimensions of a piece of timber in breadth and thickness; also, a general name for small timbers, such as the quartering for a partition, rafters, purlins, or pole-plates in a roof, &c. —2. In masonry, the same word is used to express the size of stones in length, breadth, and thickness.

SCAPE, SCAPEMENT.—The apophyge or spring of a column; the part where the shaft of a column springs out of the base, usually moulded into a concave sweep or cavetto; a congé.

SCAPPLE, SCAPPLING, SCABBLE, SCABBLING. See SCABBLE and BOASTING.

SCARCEMENT. In a wall, a set-off or table where a wall is diminished in thickness; applied chiefly to the set-off of a footing.

SCARFING.—A mode of lengthening beams, employed when it is necessary to maintain the same depth and width of the beam throughout. In doing this a part of the thickness of the timber of the length of the joint is cut from each beam, but on opposite sides, so that they may lap on each other, and the parts, when united, are bolted or hooped together. In bolting them, side-plates of iron are generally used, to protect the wood from the crushing effects of the bolts, and the ends of these plates are generally bent inwards, and inserted into the beam, as an additional security when



the beam is subjected to tension. In figs. 1 and 2 the strength of the scarf is dependent on the bolts. fig. 3 shows a scarf with the surfaces tabled and keys introduced. Fig. 4 shows fig. 1 with the surfaces tabled and keyed; fig. 5, A shows fig. 2 with keys added, and B shows the same with the parts indented; fig. 6 the simple scarf used in joining wall-plates, in which the superincumbent weight keeps the parts from being drawn asunder. See p. 147, 148, and Plate XXXIX.

SCHEME ARCH, OR SKENE ARCH.—An arch which is any segment of a circle less than a semicircle.

SCHOLA.—In ancient architecture, the margin or platform which surrounded the bath. Also, a portico corresponding to the exedra of the Greek palæstra, intended for the accommodation of the learned, who assembled there to converse.

SCIAGRAPH.—The section of a building to show its interior.

SCIOGRAPHY.—The art of projecting and delineating shadows.

SCONCE.—A branch to set a light upon, or to support a candlestick; a screen or partition to

Sconce.

cover or protect anything; the head or top of anything. The term is sometimes used as synonymous with *squinch*.

SCONCHEON (from the French *ecoinçon*).—A term applied to the portion of the side of the aperture of a door or window, from the back of the jamb or reveal to the interior of the wall.

SCOTCHING, SCUTCHING.—A method of dressing stone either by a pick or pick-shaped chisels inserted into a socket formed in the head of a hammer.

SCOTIA.—The hollow moulding in the attic base between the fillets of the tori. It takes its name from the shadow formed by it, which seems

Scotia or Trochilus Moulding

to envelope it in darkness. It is sometimes called a *casement*, and often, from its resemblance to a common pulley, *trochilus*. It is frequently formed by the junction of circular arcs of different radii.

SCREEDS.—Ledges of lime and hair about 6 or 8 inches wide, by which any surface about to be plastered is divided into bays or compartments. The screeds are 4, 5, or 6 feet apart, according to circumstances, and are accurately formed in the same plane by the plumb rule and straight-edge. They thus form gauges for the rest of the work, and when they are ready the panels or compartments between them are filled in flush with plaster, and a long float being made to traverse them, all the plaster which projects beyond them is struck off, and the whole surface reduced to the same plane.

SCREEN, BUILDERS'.—A kind of wire sieve for sifting sand, lime, gravel, &c. It consists of a rectangular wooden frame with metal wires traversing it longitudinally at regular intervals. It is propped up in nearly a vertical position, and the materials to be sifted or screened are thrown against it, when the finer particles pass through and the coarser remain.

SCREW-JACK.—A portable machine for raising great weights by the agency of a screw.

SCREWS.—Adhesion of, in Wood. See ADHESIVE FORCE OF NAILS AND SCREWS.

SCRIBE.—A spike or large nail ground to a sharp point, to mark bricks on the face and back by the tapering edges of a mould, for the purpose of cutting them and reducing them to the proper taper for gauged arches.

SCRIBE.—To mark by a rule or compasses; to mark so as to fit one piece to another. See description of the operation of scribing, text, p. 186.

SCRIBING INSTRUMENT illustrated and described. p. 200, Plate LXXXIX.

SCROLL.—In architecture, a name given to a large class of ornaments characterized generally by their resembling a narrow band arranged in convolutions or undulations.

SCUNCHEON.—The same as *sconcheon* (which see). The term is used, too, as synonymous with *squinch*, and applied to the stones or arches thrown across the angles of a square tower, to support the alternate sides of an octagonal spire. It is also used to denote the cross-pieces of timber at the angles of a frame, to give it strength and firmness. (See SQUINCH.) It is sometimes written *scutcheon*, *sconchon*, and *skewnsione*.

SCUTCHEON.—1. In ancient architecture, the shield or plate on a door, from the centre of which hung the door handle.—2. The ornamental bit of brass plate perforated with a key-hole, and placed over the key hole of a piece of furniture.

SEALING. -The operation of fixing a piece of wood or iron on a wall with plaster, mortar, cement, lead, or other binding.

SEAM OF GLASS. -The quantity of 120 lbs., of 24 stones of 5 lbs. each.

SEASONING OF TIMBER, and the means employed to increase its durability, p. 104.

SEASONING OF TIMBER.—By stoving, p. 104; by burying in dry sand, 104; by immersion in cold water, 105; by immersion in hot water, 105; by immersion in salt water, 105; by charring the surface, 105; by coating the surface with substances impervious to the air, 105; Sir Samuel Bentham's observations on, 105.

SECANTS, LINE OF, ON THE SECTOR.—Construction and use of, p. 39.

SECOND BRICKS.—Bricks of a quality next to the finest mail stocks or cutters. They are used in the principal fronts of buildings.

SECOND COAT.—In architecture, either the finishing coat as in *laid and set plaster*, or in *rendered and set plaster*; or it is the floating when the plaster is roughed in, floated, and set for paper.

SECTION. - In architecture, the projection or geometrical representation of a building supposed to be cut by a vertical plane for the purpose of exhibiting the interior, and describing the height, breadth, thickness, and manner of construction of the walls, arches, domes, &c.

SECTOR.—Construction and use of, p. 36.

SECTROID.—The curved surface between two adjacent groins. See p. 77.

SEDILIA. -The Latin name for a seat, which has come to be pretty generally applied by way of distinction to the seats for the priests in the south wall of the choir or chancel of many churches and

Sedilia, Bolton Percy, Yorkshire.

cathedrals. In this country they are usually recessed in the wall like niches, and three in number, for the use of the priest, the deacon, and sub-deacon, during part of the service of high-mass.

SELF-FACED.—A term used to denote the natural face or surface of a flag-stone, in contradistinction to dressed or hewn.

SEPTARIA.—A name given to nodules or spheroidal masses of calcareous marl, whose interior presents numerous fissures or seams of some crystallized substance, which divide the mass. When calcined and reduced to powder, these septaria furnish the valuable mortar called Roman or Parker's cement, which has the property of hardening under water.

SERVICE TREE.—Properties and uses of, p. 114.

SET SQUARES, p. 41.

SET-OFF, OR OFFSET.—The part of a wall, &c., which is exposed horizontally when the portion above it is reduced in thickness.—Also, the sloped mouldings which divide Gothic buttresses into stages. See SCARCEMENT.

SETTING.—The quality of hardening in plaster or cement; also, the fixing of stones in walls or vaults.—*Setting coat*, the best sort of plastering on ceilings or walls.

SETTING-OUT ROD.—A rod used by joiners for setting-out frames, as of windows, doors, &c.

SETTLEMENTS.—Failures in a building occasioned by sinking.

SEVEREY, SEVERY, SEBEREU, SIBARY.—A compartment in a vaulted roof; also, a compartment or division of scaffolding.

SHADING. -Methods of, p. 224.

SHADING by Flat Tints, p. 224.

SHADING by Softened Tints, p. 225.

SHADOW of a straight line.—To find the length and direction of, the projections of the straight line and of the luminous point being given, Prob. I. p. 211.

SHADOW.—To find the shadow of a straight line inclined to the horizontal plane, the projections of the luminous point and of the straight line being given, Prob. II. p. 211.

SHADOW.—To find the shadow of a straight line inclined to two planes. Prob. III. p. 212.

SHADOW.—To find the portion of the shadow of a straight line, interrupted by a plane inclined to the planes of projection, Prob. IV. p. 212.

SHADOW. -To determine the shadow of a straight line on the horizontal plane, the projections of a solar ray and of the straight line being given, Prob. VI. p. 213.

SHADOW. -To determine the shadow cast by a straight line on a vertical wall, Prob. VII. p. 214.

SHADOW.—To find the shadow cast by a straight line upon a curved surface, p. 214.

SHADOW.—To find the shadow of a circle upon the horizontal plane, p. 215.

SHADOW. -To find the shadow of a circle on the vertical plane, p. 215.

SHADOW. -To find the shadow of a circle on two planes, p. 215.

SHADOW of a circle on a circular wall, p. 215.

SHADOW of a circle situated in the plane of the luminous rays, p. 215.

SHADOW of a circle, whose horizontal projection is perpendicular to a trace of a plane passing through the luminous ray, Prob. IX. p. 216.

SHADOW. To find the shadow of a cylinder under various conditions, Prob. XI. p. 216-218.

SHADOW.—To find the shadow of the interior of a concave cylindrical surface, Prob. XII. p. 218.

SHADOW.—To find the shadow of a cone on the horizontal plane, Prob. XIII. p. 218.

SHADOW.—To find the shadow on the concave interior of a cone, Prob. XIV p. 219.

SHADOW. -To determine the shadow of a sphere on the horizontal plane, and the boundaries of shade on the sphere, Prob. XV. p. 220.

SHADOW. -To find the shadow on the concave interior of a hemisphere, Prob. XVI. p. 220.

SHADOW.—To determine the shadow in a niche, Prob. XVII. p. 221.

SHADOW.—To find the shadow of a regular hexagonal pyramid on both planes of projection, Prob. XIX. p. 221.

SHADOW. To find the shadow cast by a hexagonal prism upon both planes of projection, Prob. XX. p. 222.

SHADOW.—To determine the limit of shade in cylinders placed vertically, and likewise its shadow on both planes of projection, Prob. XXI. p. 222.

SHADOW.—To determine the limit of shade in a cylinder placed horizontally, and its shadow on both planes of projection, p. 222.

SHADOW.—To find the limit of shade in a cone, and its shadow on the two planes of projection, Prob. XXII. p. 222.

SHADOW.—To find the shadow thrown by a cone upon a sphere, Prob. XXIII. p. 222.

SHADOW.—To determine the shadow of a concave surface of revolution, Prob. XXIV. p. 223.

SHADOWS, PROJECTION OF. Introductory remarks, p. 209.

SHADOWS projected by rays of light which are parallel among themselves Prob. V. p. 213.

SHADOWS.—To find, on the circumference of a circle, the tangent points of planes passing through the light, when the circle is not in the plane of the light, Prob. X. p. 216.

SHADOWS.—To determine the shadows of a cylinder whose axis is circular (such as a ring), Prob. XVIII. p. 221.

SHAFT. -The shaft of a column is the body of it, between the base and the capital. It is also called the *fust* or *trunk* of the column. It always diminishes in diameter, sometimes from the bottom, sometimes from a quarter, and sometimes from a third of its height, and sometimes its outline is a convex curve, called the *entasis*. In the Ionic and Corinthian columns, the difference of the upper and lower diameters of the shaft, varies from a fifth to a twelfth of the lower diameter. (See COLUMN.)—*Vaulting shafts*, those which support ribs, or other parts of a vault.—*Shaft of a king post*, the part between the joggles.—*Shaft of a chimney*, the part which rises above the roof for discharging the smoke into the air.

SHAFTED IMPOST.—In mediæval architecture, an impost with horizontal mouldings, the section of the mouldings of the arch above the impost being different from that of the shaft below it. In a banded impost the sections are alike.

SHAKE. -A fissure or rent in timber, occasioned by its being dried too suddenly, or exposed to too great heat. Shakes frequently occur in growing timber from various causes.

SHANK.—Another name for the shaft of a column.—*Shanks*, or *legs*, names given to the plain space between the channels of the triglyph of a Doric frieze.

SHANTY. A hut or mean dwelling.

SHED ROOF.—The simplest kind of roof, formed by rafters sloping between a high and a low wall.

SHEERS.—Two masts or spars lashed or bolted together at or near the head, provided with a pulley, and raised to nearly a vertical position, used in lifting stones and other building materials.

SHEET PILES, SHEETING-PILES.—Piles formed of thick plank, shot or jointed on the edges, and sometimes grooved and tongued, driven closely together between the main or gauge piles of a coffer-dam or other hydraulic work, to inclose the space so as either to retain or exclude water, as the case may be. Sheeting-piles have of late been formed of iron.

SHELL-BIT.—A boring tool used with the brace in boring wood; it is shaped like a gouge, that is, its section is the segment of a circle, and when used it shears the fibres round the margin of the hole, and removes the wood almost as a solid core.

SHINGLE.—A small piece of thin wood, used like a slate for covering a roof or building. Shingles are from 8 to 12 inches long, and about 4 inches broad, thicker on one edge than the other. In America they are extensively used, and are there manufactured by machinery of a very ingenious and simple description.

SHINGLE-ROOFED.—Having a roof covered with shingles.

SHINLOG.—The brick building by which the mouth of a brick kiln is closed.

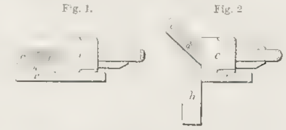
SHOE.—1. The inclined piece at the bottom of a water-trunk or lead pipe, for turning the course of the water, and discharging it from the wall of a building.—2. An iron socket used in timber framing to receive the foot of a rafter or the end of a strut.

SHOOT.—To plane straight, or fit by planing.

SHOOTING.—In joinery, the operation of planing the edge of a board straight, and out of winding.

SHOOTING BOARD.—An external *fence* or guide used in shooting or planing the edges of boards, in which the piece to be planed is narrower than the face of the plane. The annexed figures

Fig. 1. Fig. 2



are sections of shooting boards, fig. 1 being used for a rectangular joint, and fig. 2 for a mortise joint. In both figures, *a* is a piece of board on which the plane *e* lies on its side, and *b*, another piece on which the board to be planed, *d*, is laid, *c* is a stop against which the edge of the wood is pressed. There are many other forms of shooting boards.

SHORE.—A piece of timber or other material placed in such a manner as to prop up a wall or other heavy body.—*Dead-shore*, an upright piece fixed in a wall that has been cut or broken through for the purpose of making some alterations in the building.

SHOULDER. Among artificers, a horizontal or rectangular projection from the body of a thing.—*Shoulder of a tenon*, the plane transverse to the length of a piece of timber from which the tenon projects. It does not however, always lie in the plane here defined, but sometimes lies in different planes. See p. 147.

SHOULDERING. In slating, a fillet of haired lime laid under the upper edge of the smaller and thicker kind of slates, such as those of Argyleshire, to raise them there and prevent their being open

at the overlap, and also to make the joint weather-tight.

SHREDDINGS.—In old buildings, short, light pieces of timber, fixed as bearers below the roof, forming a straight line with the upper side of the rafters.

SHRINE.—1. A reliquary, or box for holding the bones or other remains of departed saints. The primitive form of the shrine was that of a small church with a high-ridged roof, and similar to the

Portable Shrine, Malmesbury Abbey.

hog-backed tombs of the ancient Greeks, still seen in Anatolia. Hence,—2. A tomb, of shrine-like configuration; and,—3. A mausoleum of a saint, of any form; as the shrine of St. Thomas à Becket at Canterbury.

SHUTTERS.—The boards which close the aperture of a window. The shutters of principal windows are usually in two divisions or halves, each subdivided into others, so that they may be received within the boxings into which the shutters are folded or fall back. The front shutter is of the exact breadth of the boxing, and also flush with it; the others, which are hidden in the boxing, are somewhat less in breadth, and are termed *backfolds* or *backflaps*. Shutters, as above defined, may be considered as the doors of window openings, and are formed upon the same principles as doors, but sometimes in place of being hinged to fold back, they are suspended and counterbalanced like window-sashes, so as to slide; and they are also made of laths jointed together and wound round a roller placed either horizontally above the soffit, or vertically at the side of the opening. See p. 188.

SHUTTERS.—Linings for, p. 188.

SIBARY. See SEVEREY.

SICAMORE. See SYCAMORE.

SIDE-HOOK.—In joinery, a rectangular prismatic piece of wood, with a projecting knob at the ends of its opposite sides. The use of the side-hook is to hold a board fast, its fibres being in the direction of the length of the bench, while the workman is cutting across the fibres with a saw or grooving-plane, or in *traversing* the wood, which is planing it in a direction perpendicular to the fibres.

SIDE-POSTS.—In architecture, a kind of truss-posts placed in pairs, each disposed at the same distance from the middle of the truss, for the purpose of hanging the tie-beam below. In extended roofs, two or three pairs of side-posts are used. Throughout the text they are called *primary* and *secondary queen-posts*.

SIDE-TIMBERS, SIDE-WAVERS.—The former is the Somersetshire, and the latter the Lincolnshire local name for *purlins*.

SIEGE.—The name given in Scotland to the bench or other support on which a mason places his stone to be hewn, a term derived from the French. In England it is termed a *banker*.

SILL.—The horizontal piece of timber or stone at the bottom of a framed case; such as that of a door or window.—*Ground sills* are the timbers on the ground which support the posts and superstructure of a timber building. -The word *sill* is also used to denote the bottom pieces which support quarter and truss partitions, and the flat stones used to form the bottom of a drain are also called *sills*.

SILVER FIR.—Properties and uses of, p. 118.

SINES, Line of, on the Sector.—Construction and use of, p. 39.

SINGLE FLOOR, SINGLE FLOORING, SINGLE JOISTS, SINGLE-JOIST FLOOR.—Applied to naked flooring, consisting of bridging-joists only, p. 150.

SINGLE HUNG.—Applied to a window with two sashes, when one only is moveable.

SISSOO.—A tree well known throughout the Bengal presidency, and highly valued on account of its timber, which furnishes the Bengal ship-builders with their crooked timbers and knees. It is universally employed both by Europeans and natives of the north-west provinces of India, where strength is required. It is the *Dalbergia sissoo* of botanists, and belongs to the papilionaceous division of the natural order Leguminosæ.

SITE.—The position or seat of a building; the place whereon it stands.

SKETCH.—An outline or general delineation of anything; a first rough or incomplete draught of a plan or any design; as the *sketch* of a building.

SKEW.—A term used in Scotland for a gable-coping or factable.

SKEW, OR ASKEW.—Oblique; as a *skew*-bridge.

SKEW-ARCH.—An arch whose direction is not at right angles to its axis; it is also frequently termed an *oblique arch*.

SKEW-BACK.—The sloping abutment in brick-work or masonry for the ends of the arched head of an aperture. In bridges, it is the course of masonry forming the abutment for the voussoirs of a segmental arch, and in iron bridges it is the abutment formed for the ribs.

SKEW-BRIDGE.—A bridge in which the passages over and under the arch intersect each other obliquely. In conducting a road or railway through a district in which there are many natural or artificial watercourses, or in making a canal through a country in which roads are frequent, such intersections very often occur. Before the introduction of railways skew-bridges were seldom erected, it being more usual to build the bridge at right angles, and to divert the course of the road or the stream to accommodate it. But in a railway, and sometimes in a canal, such a deviation from the straight line of direction is often inadmissible, and it therefore becomes necessary to build the bridge obliquely.

SKEW-BRIDGES illustrated and described:—

	Plate.	Page
Skew-bridge over the river Don,	L.	162
Skew-bridge on the system of M. Somet,	LIII.	164
Skew-bridge over the Leith Branch Railway, near Portobello,	LV.	170

SKEW-CORBEL, SKEW-PUT, SKEW-TABLE.—

A A, Skew-corbels.

A stone built into the bottom of a gable to form an abutment for the coping.

SKEW-FILLET.—A fillet nailed on a roof along the gable coping, to raise the slates there and throw the water away from the joining.

SKIRTING, SKIRTING-BOARD.—The narrow vertical board placed round the margin of a floor. Where there is a dado this board forms a plinth for its base; otherwise it is a plinth for the room itself. See p. 186.

SKIRTING.—Method of scribing, p. 200.

SKY-DRAIN.—A cavity formed round the walls of a building, to prevent the earth from lying against them and causing dampness, called also *air-drain* and *dry-drain*.

SKY-LIGHT.—A window placed in the top of a house, or a frame consisting of one or more inclined planes of glass placed in a roof to light passages or rooms below.

SKY-LIGHTS.—To find the length and backing of an hip, p. 189.

SKY-LIGHTS, Octagonal, Domical, &c.—To find the ribs, window-bars, &c., p. 190.

SLABS.—The outside planks or boards, mainly of sap-wood, sawn from the sides of round timber.

SLACK-BLOCKS.—The wedges on which the centres used in the construction of bridges are supported, p. 173, 175.

SLAP-DASH.—A provincial term for *rough-casting*.

SLATE BOARDING.—Close boarding covering the rafters of a roof, on which the slates are laid. In Scotland, called *sarking*.

SLATES.—The various sizes of slates are thus named:—

	ft.	in.		ft.	in.
Doubles,	1	1	×	0	6
Ladies,	1	3	×	0	8
Countesses,	1	8	×	0	10
Duchesses,	2	0	×	1	0
Imperials,	2	6	×	2	0
Queens,	3	0	×	2	0
Welsh Longs, or Rags,	3	0	×	2	0

A square of slating is 100 superficial feet. A square of Westmoreland or Welsh Rag slating will weigh 10 cwts., and of Duchesses, Countesses, or Ladies slating 6 cwts.

		Squares.
1 ton of Westmoreland Slates will cover		2
1 ton of Welsh Rags	,,	1½ to 2
1000 Duchess Slates	,,	9
1000 Countess Slates	,,	5
1000 Ladies Slates	,,	3¼
1000 Tavistock Slates	,,	2¼

SLEEPERS.—Pieces of timber on which are laid the ground joists of a floor, and also, and more usually, the ground joists themselves. Formerly the term was used to denote the valley-rafters of a roof.—In railways, sleepers are beams of wood or blocks of stone firmly imbedded in the ground to sustain the rails, which are usually fixed to the sleepers by means of cast-iron supports called *chairs*.

SLIDING-RULE.—A mathematical instrument or scale, consisting of two parts, one of which slides along the other, and each having certain sets of numbers engraved on it, so arranged that when a given number on the one scale is brought to coincide with a given number on the other, the product or some other function of the two numbers is obtained by inspection. The numbers may be adapted to answer various purposes, and slide rules are made to suit the necessities of the carpenter, engineer, gauger, &c.

SLIP-FEATHER. p. 182.

SLIT-DEAL.—Fir boards a full half-inch thick.

SLOP-MOULDING.—In brick-making, that kind of moulding in which water is used to free the clay from the mould, in place of the sand used in pallet-moulding.

SMOOTHING-PLANE. See PLANE.

SNECKING.—A peculiar method of building in rubble-work. See RUBBLE.

SNIPE'S-BILL PLANE.—In joinery, a plane with a sharp arris for forming the quirks of mouldings.

SOCKET-CHISEL.—A chisel made with a socket; a stronger sort of chisel, used by carpenters for mortising, and worked with a mallet.

SOCLE.—A flat square member of less height than its horizontal dimension, serving to raise pedestals, or to support vases, or other ornaments. It differs from a pedestal in being without base or capital. A *continued socle* is one continued round a building.

SOFFIT.—The under side of the lintel or ceiling of an opening; the lower surface of a vault or arch. It also denotes the under horizontal surface of an architrave between columns, and the under surface of the corona of a cornice.

SOFFIT-LINING. p. 188.

SOLAR, SOLLAR.—A loft; an upper chamber. See SOLLAR.

SOLID OF REVOLUTION generated by an ogee curve.—To describe the section of a, p. 69, Plate I. Fig. 10.

SOLID OF REVOLUTION generated by a lancet-formed curve.—To describe the section of a, p. 69, Plate I. Fig. 11.

SOLIDS.—Sections of, p. 68.

SOLIDS.—Coverings of, p. 69.

SOLIDUM.—The die of a pedestal.

SOLIVE.—A joist, rafter, or piece of wood, either slit or sawed. The word is French, and is sometimes, though rarely used by English writers.

SOLLAR.—Originally an open gallery or balcony at the top of a house, exposed to the sun; but latterly used to signify any upper room, loft, or garret.

SOMMER. See SUMMER.

SOUND TIMBER. -Krafft's mode of judging of, p. 93.

SOUND-BOARDING.—The sound-boarding of floors consists of short boards generally, and preferably, split, not sawn, which are disposed transversely between the joists, and supported by fillets fixed to the sides of the joists, for holding the substance called pugging, intended to prevent sound from being transmitted from one story to another. See PUGGING. In Scotland, sound-boarding is termed *deafening-boarding*.

SOUNDING-BOARD, OR SOUND BOARD.—A board or structure placed over a pulpit or other place occupied by a public speaker, to reflect the sound of his voice, and thereby render it more audible. Sounding-boards are generally flat, and placed horizontally, but concave parabolic sounding-boards have been tried, and found to answer better. See p. 190, and Plate LXXXIII[a].

SOURCE, SOUSE.—A support or under prop.

SPAN.—In architecture, an imaginary line across the opening of an arch or roof, by which its extent is estimated. See ARCH.

SPAN-PIECE.—A name given in some places to the collar-beam of a roof.

SPAN-ROOF.—A name sometimes given to the common roofing, which is formed by two inclined

planes or sides, in contradistinction to a *shed* or *lean-to*.

SPANDREL.—The irregular triangular space comprehended between the outer curve or extrados of an arch, a horizontal line drawn from its apex, and a perpendicular line from its springing. In Gothic architecture, spandrels are usually ornamented with tracery, foliage, &c. See Plate XXXII. Fig. 5, and Door-head with Spandrels, under DRIPSTONE.

SPANDREL BRACKETING.—A cradling of brackets which is placed between curves, each of which is in a vertical plane, and in the circumference of a circle whose plane is horizontal.

SPANDREL WALL.—A wall built on the back of an arch filling in the spandr[illegible].

SPAR.—A small beam or rafter. In architecture, spars are the common rafters of a roof, as distinguished from the principal rafters.

SPECIFICATION.—A statement of particulars, describing the manner of executing any work about to be undertaken, and the quality, dimensions, and peculiarities of the materials to be used.

SPERE.—An old term for the screen across the lower end of a dining-hall, to shelter the entrance.

SPERVER.—An old term for the wooden frame at the top of a bed or canopy. Sometimes the term includes the *tester*, or head piece. It signified originally a tent.

SPHERE, OR GLOBE, is a solid bounded by a curved surface, every point of which is equidistant from a point within it called the centre.—To find the surface of a sphere, or of any segment or zone of it. Rule: Multiply the circumference of a great circle of the sphere by the axis, or by the part of it corresponding to the segment or the zone required; the product will be the surface. -To find the solid content of a sphere. Rule: Multiply the cube of the axis by ·5236.—To find the solid content of a segment of a sphere. 1. When the axis and height of segment are given. Rule: From three times the axis subtract twice the height, and multiply the remainder by the square of the height and by ·5236. 2. When the height and radius of the base are given. Rule: To three times the square of the radius add the square of the height, multiply the sum by the height, and by ·5236. The product is the content.

To find the content of the middle zone of a sphere. Rule: From the square of the axis or greatest diameter subtract one-third of the square of the height, then multiply the remainder by the height and by ·7854.—To find the content of any zone of a sphere. Rule: Add the square of the radii of the two ends to one-third of the square of the height, then multiply the sum by twice the height and by ·7854.

SPHERE.—To find the limits of shade on, and the shadow thrown by a sphere, p. 220.

SPHERE penetrated by a cylinder.—To find the projections of, p. 64.

SPHERE.—To find the projections of a sphere penetrated by an oblique scalene cone, p. 64.

SPHERE.—Development of the surface of a sphere, p. 73.

SPHERE.—To find the projections of a scalene cone penetrating a sphere, p. 64.

SPHERE.—Tangent plane to a sphere, p. 61.

SPHERE.—To construct the sections of a sphere by a plane, p. 60.

SPHERE.—To describe the section of a sphere, p. 68, Plate I. Fig. 7.

SPHERE, The.—Development of, p. 72.

SPHERICAL BRACKETING.—Brackets so formed, that the face of the lath-and-plaster work which they support makes a spherical surface.

SPHERICAL PENDENTIVES.—To cover the ceiling of a room with, p. 80.

SPHERICAL VAULT.—To determine the heights of the divisions of a, p. 83.

SPHERO-CYLINDRIC GROIN.—One formed by the intersection of a cylindrical vault with a spherical vault of greater dimensions. See p. 77.

SPHEROID.—A body or figure approaching to a sphere, but not perfectly spherical. In geometry, a spheroid is a solid, generated by the revolution of an ellipse about one of its axes. When the generating ellipse revolves about its longer or major axis, the spheroid is *oblong* or *prolate*: when about its less or minor axis, the spheroid is *oblate*. The earth is an oblate spheroid, that is, flattened at the poles, so that its polar diameter is shorter than its equatorial diameter.

SPHEROIDAL BRACKETING.—Bracketing which has a spheroidal surface.

SPINDLE, CIRCULAR.—A circular spindle is the solid generated by the revolution of a segment of a circle about its chord.—To find the solid content of a circular spindle. Rule: Multiply the area of the generating segment by half the central distance, and subtract the product from one-third of the cube of half the length of the spindle, then four times the remainder multiplied by 3·1416 will give the content.

SPIRE.—The pyramidal or conical termination of a tower or turret. The earliest spires were merely pyramidal or conical roofs, specimens of which still exist in Norman buildings, as that of the tower of Than Church in Normandy. These roofs, becoming gradually elongated, and more and more acute, resulted at length in the elegant tapering spire; among the many existing examples of which, probably, that of Salisbury is the finest. In mediæval architecture, to which alone they are appropriate, spires are generally square, octagonal, or circular in plan; they are sometimes solid, more frequently hollow, and are variously ornamented with bands encircling them, with panels more or less enriched, and with spire lights, which are of infinite variety. Their angles are sometimes crocketted, and they are almost invariably terminated by a finial. In the later styles the general pyramidal outline is obtained by diminishing the diameter of the building in successive stages, and this has been imitated in modern spires, in which the forms and details of classic architecture have been applied to structures essentially mediæval. The term spire is sometimes restricted to signify such tapering buildings, crowning towers or turrets, as have parapets at their base. When the spire rises from the exterior of the wall of the tower without the intervention of a parapet, it is called a *broach*.

SPIRE-LIGHTS.—The windows of a spire.

SPIRIT-LEVEL.—An instrument employed for determining a line or plane parallel to the horizon, and also the relative heights of ground at two or more stations. It consists of a tube of glass nearly filled with spirit of wine or distilled water, and hermetically sealed at both ends; so that when held with its axis in a horizontal position, the bubble of air which occupies the part not filled with the liquid rises to the upper surface, and stands exactly in the middle of the tube. The tube is placed within a brass or wooden case, having a long opening on the side which is to be uppermost, so that the position of the air-bubble may be readily seen. When the instrument thus prepared is laid on a horizontal surface, the air bubble stands in the very middle of the tube; when the surface slopes, the bubble rises to the higher end. It is used by carpenters and joiners for ascertaining whether the upper surface of any work be horizontal. When employed in surveying, it is attached to a telescope, the telescope and tube being fitted to a frame or cradle of brass, which is supported on three legs.

SPLAY.—A sloped surface, or a surface which makes an oblique angle with another; as when the

Plan Section of Gothic Window

A A, The internal Splay

op[illegible] wall for a door, window, &c., widens inwards. A large chamfer is called a *splay*.

SPOKE-SHAVE.—A sort of small plane used for dressing the spokes of wheels and other curved work, where the common plane cannot be applied.

SPOON-BIT.—A hollow bit with a taper point for boring wood.

SPRING BEVEL OF A RAIL.—The angle which the top of the plank makes with a vertical plane which has its termination in the concave side, and touches the ends of the rail-piece. See p. 203.

SPRING COMPASSES.—Instructions in the use of, p. 31.

SPRINGER.—The point where the vertical support of an arch terminates, and the curve begins. The lowest of the series of voussoirs of which an arch is formed, being the stone which rests immediately upon the impost. See woodcut, ARCH. The bottom stone of the coping of a gable is sometimes called a *springer*.

SPRINGING.—The point from which an arch springs or rises. -*Springing course*, the horizontal course of stones from which an arch springs or rises.

In carpentry, in boarding a roof, the setting the boards together with bevel joints, for the purpose of keeping out the rain.

SPRUCE.—Description and uses of, see p. 117.

SPUR.—Often used as a synonyme for *strut*.

SQUARE.—To construct a square, the sides of which shall be equal to a given straight line, Prob. XXV. p. 9.—To describe a square equal to a given rectangle, Prob. XXVI. p. 9.—To describe a square equal to two given squares, Prob. XXIX. p. 10.—To describe a square equal to any number of given squares, Prob. XXX. p. 10.—To describe a square equal to the difference between two unequal squares, Prob. XXXI. p. 10.—To describe a square equal to any portion of a given square, Prob. XXXII. p. 10.—To describe a square about a given circle, Prob. XLVII. p. 14.—To describe a square equal to a given circle, Prob. LXXV. p. 20, and Prob. LXXVI. p. 20.

SQUARE FRAMED.—In joinery, a work is said to be *square framed* or *framed square*, when the framing has all the angles of its styles, rails, and mountings square without being moulded.

SQUARE FRAMING. p. 185.

SQUARE SHOOT.—A wooden trough for discharging water from a building.

SQUARE STAFF.—A square fillet used as an angle staff in place of a bead-moulding, in rooms that are prepared for papering.

SQUARING A HANDRAIL.—The method of cutting a plank for a rail to a staircase, so that all the vertical sections may be rectangular.

SQUARING OF TIMBER.—Methods usually adopted, p. 99.

SQUINCH.—The small pendentive arch formed across the angle of a square tower, to support the side of a superimposed octagon. The

application of the term to these pendentives may have been suggested by their resemblance to a corner cupboard, which was also called a *squinch* or *sconce*.

SQUINT.—In mediæval architecture, a name given to an oblique opening in the wall of a church. Squints were generally so placed as to afford a view of the high altar from the transept or aisles.

STACK OF WOOD.—A pile containing 108 cubic feet.

STAFF-ANGLE. See SQUARE STAFF.

STAFF-BEAD. See ANGLE-BEAD.

STAGE.—The part between one sloping projection and another, in a Gothic buttress. Also, the horizontal division of a window separated by transoms. Sometimes the term is used to signify a floor, a story.

STAIR.—A step, but generally used in the plural to signify a succession of steps, arranged as a way between two points at different heights in a building, &c. A succession of steps in a continuous line is called a *flight of stairs;* the termination of the flight is called a *landing*. Stairs are further distinguished by the various epithets, dog legged, newelled, open newelled, &c.

STAIRCASE.—The building or apartment which contains the stairs, see p. 196.

STAIRS AND HANDRAILING.—Introductory remarks, p. 195.

STAIRS.—Simple contrivances as substitutes for stairs, p. 195.—Contrivances for economizing space in stairs, p. 195.

STAIRS.—Definitions of terms, p. 196.

STAIRS.—Method of laying down the plan of:

As applied to dog-legged stairs, . .	198
As applied to newel stairs, . . .	198
As applied to geometrical stairs, . .	199
As applied to elliptical stairs, . . .	199

STAIRS.—Method of setting out when the building is erected, or its general plan understood, p. 196.

STAIRS.—Methods of lessening the inequality of width between the ends of the winding steps by calculation, and also graphically, p. 199.—Formation of carriages for various kinds of stairs, p. 199, 200.

STAKE FALD HOLES.—A local name for putlog holes.

STALLS.—Fixed seats, inclosed either wholly or partially at the back and sides.—The choir or chancel of a cathedral, collegiate church, and even of most small churches, had, previous to the Reformation, one or more ranges of wooden stalls at its west end, the seats of which were separated from

each other by large projecting elbows. The stalls were often enriched by panelling, and surmounted by canopies of tabernacle work, enriched with

Stalls, Higham Ferrers Church, Northamptonshire.

crochets, pinnacles, &c. Many beautiful examples of these yet remain.

STANCHION.—A prop or piece of timber giving support to one of the main parts of a roof; also, one of the upright bars, wood or iron, of a window, screen, railing, &c.

STANDARD.—In joinery, any upright in a framing, as the quarters of partitions, the frame of a door, and the like.

STANZA.—An apartment or division in a building.

STARLINGS, or STERLINGS.—An assemblage of piles driven round the piers of a bridge to give them support. They are sometimes called *stilts*.

STEENING, or STEANING.—The brick or stone wall, or lining of a well or cess-pool, the use of which is to prevent the irruption of the surrounding soil.

STEEPLES, TOWERS, AND SPIRES of TIMBER.—Construction of, described p. 145, 146, and illustrated in Plate. XXXV., XXXVa, and XXXVI.

STEP.—One of the gradients in a stair; it is composed of two fronts, one horizontal, called the *tread*, and one vertical, called the *riser*.

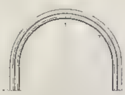
STEREOBATE.—The same as *stylobate* (which see).

STEREOGRAPHY.—The act or art of delineating the forms of solid bodies on a plane; a branch of solid geometry which shows the construction of all solids which are regularly defined. See p. 46.

STEREOTOMY.—A branch of stereography, which teaches the manner of making sections of solids under certain specified conditions.

STICKING.—The operation of forming mouldings by means of a plane, in distinction from the operation of forming them by the hand.

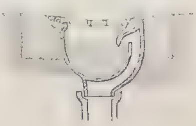
STILTED ARCH.—A term applied to a form of the arch used chiefly in the twelfth century. In



Stilted Arch

this form the arch does not spring immediately from the imposts, but is raised as it were upon stilts for some distance above them.

STINK-TRAP.—A contrivance to prevent the passage of noxious vapours from sewers and drains.



Section of Drain-trap.

It is variously formed. The figure shows one of the forms commonly used.

STIRRUP PIECE.—A name given to a piece of wood or iron in framing, by which any part is suspended; a vertical or inclined tie.

STOCK AND BITS. See BRACE AND BITS.

STOCKHOLM TIMBER. See PINUS SYLVESTRIS, p. 116, 117.

STOOTHING.—A provincial term for *battening*.

STOPS.—In joinery, pieces of wood nailed on the frame of a door to form the recess or rebate into which the door shuts.

STORY.—A stage or floor of a building, called in Scotland a *flat;* a subdivision of the height of a house; or a set of rooms on the same floor or level. A story comprehends the distance from one floor to another; as a *story* of nine, ten, twelve, or sixteen feet elevation. Hence each floor terminating the space is called a *story;* as a house of one *story*, of two *stories*, of five *stories*. In the United States, the floor next the ground is the first *story;* in France and England this is called the ground-floor, and the second from the ground is called the first floor or *story*.

STORY-POSTS.—Upright posts to support a floor or superincumbent wall, through the medium of a beam placed over them.

STORY-ROD.—A rod used in setting up a staircase, equal in length to the height of a story of a house, and divided into as many parts as there are intended to be steps in the stair, so that the steps may be measured, and distributed with accuracy. See p. 196.

STOUP.—A basin for holy water, usually placed in a niche at the entrance of Roman Catholic

Stoup, Maidstone Church, Kent

churches, into which all who enter dip their fingers and cross themselves.

STRAIGHT ARCH.—The term is usually and properly applied to an arch over an aperture in which the intrados is straight. An arch consisting of straight lines and a pointed top, comprising two sides of an equilateral triangle, is also called a *straight arch*.

Straight Arch.

STRAIGHT-EDGE.—In joinery, a slip of wood made perfectly straight on the edge, and used to ascertain whether other edges are straight, or whether the face of a board is planed straight. It is made of different lengths, according to the required magnitude of the work. Its use is obvious, as its application will show whether there is a coincidence between the straight-edge and the surface or edge to which it is applied. It is also used for drawing straight lines on the surface of wood. See WINDING STICKS, p. 44.

STRAIGHT-JOINT FLOOR, p. 185.

STRAIGHT LINE.—To bisect a straight line, Prob. IX. p. 7.—To divide a straight line into any number of equal parts, Prob. X. p. 7.—To find the shadow of a straight line inclined to the horizontal plano, p. 211.—To find the shadow of a straight line inclined to two planes, p. 212.—To find the shadow of a straight line intercepted by a plane inclined to the plane of projection, p. 212.—To determine the shadow of a straight line on the horizontal plane, p. 213.—To determine the shadow of a straight line on the vertical plane, p. 214.—Shadow thrown by a straight line on a curved surface, p. 214.

STRAIGHT STAIRS. p. 196.

STRAIN AND STRENGTH OF MATERIALS. p. 123.

STRAINING PIECE.—A beam placed between two opposite beams to prevent their nearer approach; as rafters, braces, struts, &c. If such a piece performs also the office of a sill, it is called a *straining sill*.

STRAINING PIECES in a partition. Plate XLV. Fig. 1, *h*; Fig. 2, No. 2, *f*; Fig. 3, No. 1, *f*, p. 155.

STRAP.—In carpentry, an iron plate placed across the junction of two timbers for the purpose of securing them together. See Plates XXVII.–XXIX., and p. 146.

STRENGTH AND STRAIN OF MATERIALS. p. 123.

STRETCHED OUT.—In architecture, a term applied to a surface that will just cover a body so extended that all its parts are in a plane, or may be made to coincide with a plane.

STRETCHER.—A brick or stone laid horizontally with its length in the direction of the face of the wall. It is thus distinguished from a *header*, which is laid lengthwise across the thickness of the wall, so that its head or end is seen in the external face of the wall.

STRETCHING COURSE.—A course of stretchers; that is, of stones or bricks laid horizontally with their lengths in the direction of the face of the wall. See HEADING COURSE.

STRIKE-BLOCK.—A plane shorter than a jointer, used for shooting a short joint.

STRIKING.—In architecture, the drawing of lines on the surface of a body; the drawing of lines on the face of a piece of stuff for mortises, and cutting the shoulders of tenons. In joinery, the act of running a moulding with a plane.—*The striking of a centre* is the removal of the timber framing, upon which an arch is built after its completion.

STRIKING CENTRES. p. 175.

STRING-BOARD, STRING-PIECE, OR STRINGER.—A board placed next to the well-hole in wooden stairs, and terminating the ends of the steps.

STRING-COURSE.—A narrow moulding or projecting course continued horizontally along the face of a building, frequently under windows. It is sometimes merely a flat band.

STRINGS.—Formation of, by various methods, p. 200, 201.

STRINGS in staircases. p. 196.

STRUT.—Any piece of timber in a system of framing which is pressed or crushed in the direction of its length.

STRUTS.—In flooring, short pieces of timber about $1\frac{1}{2}$ inch thick, and 3 to 4 inches wide, inserted

between flooring joists sometimes diagonally, as in the figure, to stiffen them. See p. 151, and illustrations of various modes of strutting, Plate XLII.

STRUTS AND TIES.—To find whether a piece of timber in a system of framing is acting as a *strut* or a *tie*. p. 122.

STRUTTING BEAM, STRUT-BEAM.—An old name for a *collar-beam*.

STRUTTING-PIECE.—The same as *straining-piece*.

STUB-MORTISE.—A mortise which does not pass through the whole thickness of the timber.

STUCCO.—A word applied as a general term to plaster of any kind, used as a coating for walls, and to give them a finished surface. The third coat of three-coat plaster, consisting of fine lime and sand, is termed stucco; it is floated and trowelled. There is a species called *bastard stucco*, in which a small portion of hair is used. It is merely floated and brushed with water.

STUCK MOULDINGS.—In joinery, mouldings formed by planes, instead of being wrought by the hand.

STUDS.—In carpentry, posts or quarters placed in partitions, about a foot distant from each other.

STUDWORK.—A wall of brick-work built between studs.

STUMP-TENON. p. 182.

STYLE. See STILE, and p. 186.

STYLOBATE.—In architecture, in a general sense, any sort of basement upon which columns are placed to raise them above the level of the ground or floor; but in its technical sense, it is applied only to a continuous unbroken pedestal, upon which an entire range of columns stand, contradistinguished from pedestals, which are merely detached fragments of a stylobate placed beneath each column.

SUBPLINTH.—A second and lower plinth placed under the principal one in columns and pedestals.

SUBSELLIA.—The small shelving seats in the stalls of churches or cathedrals, made to turn up upon hinges so as to form either a seat, or a form

to kneel upon, as occasion required. They are still in constant use on the Continent, though compara-

[illegible]

tively seldom used in England. They are also called *misereres*.

SUMMARY of rules for calculating the strength of timber, p. 130.

SUMMER.—1. A large stone, the first that is laid over columns and pilasters. The first voussoir of an arch above the impost. —2. A large timber supported on two stone piers or posts, serving as a lintel to an opening. —3. A large timber or beam laid as a bearing beam; a girder.

SUMMERINGS, SUMMER TREE. The same as *summer* (which see).

SUNDSVALL TIMBER. See PINUS SYLVESTRIS, p. 116, 117.

SUPERCILIUM. — In ancient architecture, the upper member of a cornice. It is also applied to the small fillets on each side of the scotia of the Ionic base.

SURBASE. -The crowning moulding or cornice of a pedestal; a border or moulding above the base; as the mouldings immediately above the base of a room.

SURBASED.—Having a surbase, or moulding above the base.

SURBASED ARCH.—An arch whose rise is less than the half-span.

SURBASEMENT. -The trait of any arch or vault which has the form of a portion of an ellipsis.

SURFACES of double curvature.—Development of, p. 72.

SUSPENDED OR HUNG SASHES. p. 187.

SWEDISH TIMBER. See PINUS SYLVESTRIS, p. 116, 117.

SWEEPS AND VARIABLE CURVES. p. 44.

SWELLING of the Shaft of a Column. See ENTASIS

SYCAMORE, The.—Description of the properties and uses of, p. 113

SYSTYLE. — An intercolumniation of two diameters.

T.

T SQUARE.—Construction of, and mode of using, described, p. 43.

TABBY.—A mixture of lime with shells, gravel, or stones in equal proportions, with an equal proportion of water, forming a mass, which, when dry, becomes as hard as rock. This is used in Morocco instead of bricks for the walls of buildings.

TABLE.—Found in its compounds *grass-table, ground table, earth table, fictable*.

TABLE of the Properties of Timber, p. 133.

TABLET.—A term used by Rickman to denote projecting mouldings and strings, among which he includes the cornice and drip-stones.

TABLING. — 1. A term sometimes used in Scotland to designate the coping of the walls of very common houses. —2. The indenting of the ends of the piece forming a scarf, so that the joint will resist a longitudinal strain. See illustration to SCARF.

TÆNIA, TENIA. — The band or fillet which separates the Doric frieze from the architrave.

TAIL IN. -To fasten anything by one of its ends into a wall.

TAIL TRIMMER.—A trimmer next to the wall, into which the ends of joists are fastened to avoid flues.

TAKING DIMENSIONS.—The manner of, p. 67.

TALON. —The French term for the ogee moulding.

TALUS.—A slope or inclined plane

TAMBOUR.—1. A term applied to the naked part of Corinthian and Composite capitals, which bears some resemblance to a drum. It is also called the *vase*, and *campana*, or the *bell*. Also, the wall of a circular temple surrounded with columns, and the circular vertical part of a cupola —2. A cylindrical stone, such as one of the courses of the shaft of a column.

TANG.—The part of chisels and similar tools inserted in the handle.

TANGENT PLANE. -To right and oblique cylinders, p. 60, 61.—To a cone, p. 61.—To a sphere, p. 61, 62.

TANGENT PLANES to curved surfaces, p. 60.

TANGENTS. The line of, on the Sector.—Construction and use of, p. 39.

TANGENTS.— Logarithmic line of, on the Sector, p. 41.

TAPER SHELL-BIT.—A species of boring-bit used by joiners. It is conical both within and without, and its horizontal section is a crescent, the cutting edge being the meeting of the interior and exterior conical surfaces. Its use is for widening holes in wood.

TASSELS. Pieces of board which tie under the ends of the mantel tree; called also *torsels*.

TAXIS.—In ancient architecture, a term used to signify that disposition which assigns to every part of a building its just dimensions. It is synonymous with *ordonnance* in modern architecture.

TEAK. -Properties and uses of, p. 112.

TEAZE TENON.—A tenon on the top of a tenon, with a double shoulder and tenon from each, for supporting two level pieces of timber at right angles to each other.

TELAMONES. – Figures of men employed as columns or pilasters to support an entablature, in the same manner as Caryatides. They were called *Atlantes* by the Greeks. See ATLANTES

TEMPLATE.—A short piece of timber laid under the end of a beam or girder, resting on a wall, particularly in brick buildings, to distribute the weight over a large space.

TEMPLET. — A pattern or mould used by masons, machinists, smiths, shipwrights, &c., for shaping anything by. It is made of tin or zinc plate, sheet iron, or thin board, according to the use to which it is to be applied

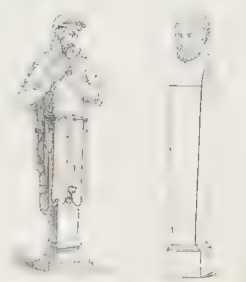
TENON.—The end of a piece of wood cut into the form of a rectangular prism, which is received into a cavity in another piece, having the same shape and size, called a *mortise*. It is sometimes written *tenant*. See MORTISE, and p. 147.

TENON SAW (often corruptly called *tenor saw*) -A small saw with a brass or steel back, used for cutting tenons.

TENONING MACHINE.—Furness', p. 193.

TEREDO NAVALIS, fatally injurious to timber, p. 105.

TERMINUS -A pillar statue; that is, either a half statue, or bust, not placed upon, but incorporated with, and, as it were, immediately springing out of, the square pillar which serves as its pedestal.



T[illegible] Statue of Pan. Antique Term[illegible]

The pillar part is generally made to taper downwards, or made narrower at its base than above. Termini are employed, not as insulated pillars, but as pilasters, forming a small order or attic, or a decoration to gateways, doors, &c.

TETRAEDRON. See TETRAHEDRON.

TETRAGON. -A figure having four angles.

TETRAHEDRON, TETRAEDRON. -One of the five regular solids. It is bounded by four equilateral triangles. —To find its surface. Rule: Multiply the square of its linear side by 1·7320508. —To find its solidity. Rule: Multiply the cube of its linear side by 0·1178511.

TETRAHEDRON. -The horizontal projection of a tetrahedron being given, to find the vertical projection, p. 52.—A point in one of the projections of a tetrahedron being given, to find the point in the other projection, p. 52.

TETRAHEDRON.—To find the projection of the section of a tetrahedron cut by a plane, p. 52.

TETRAHEDRON.—To find the projections of a tetrahedron when inclined to the horizontal plane, p. 53.

THOLE, THOLUS.—In ancient architecture, a dome or cupola; any circular building.

THOLOBATE —In architecture, the substructure on which a dome rests.

THREE-COAT WORK.—Plastering which consists of pricking up or roughing in, floating, and a finishing coat.

THROAT.—A channel or groove worked in the projecting part of the under side of a string-course, coping, &c., to throw off the water and prevent it running inwards towards the wall.

THROUGH STONE.—A bond stone or header.

TIE.—In architecture, a timber-string, chain, or a rod of metal connecting and binding two bodies together which have a tendency to separate or diverge; such as *tie*-beams, diagonal *ties*, truss-posts, &c. —*Angle tie*, angle-brace. See under ANGLE.

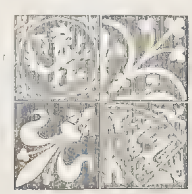
TIE-BEAM.—The beam which connects the feet of a pair of principal rafters, and prevents them from thrusting out the wall See ROOF.

TIE-ROD.—The dimensions of iron tie-rods for roofs of various spans, assuming the angle of inclination of the principals at 30°, are given by Mr. W. E. Tarn as follows:—

Span [illegible]	Strain on Tie rod in lbs.	[illegible]
20	6,600	$\frac{7}{8}$
25	8,250	1
30	9,900	$1\frac{1}{8}$
40	13,200	$1\frac{1}{4}$
50	16,500	$1\frac{3}{8}$
60	19,800	$1\frac{1}{2}$
70	23,100	$1\frac{5}{8}$
80	26,400	$1\frac{3}{4}$
90 }	29,700 }	$1\frac{7}{8}$
100 }	33,000 }	

TIGE.—The shaft of a column.

TILE. A kind of thin brick or plate of baked clay, used for covering the roofs of buildings, and occasionally for paving floors, constructing drains, &c. The best qualities of brick-earth are used for making tiles, and the process is similar to that of brickmaking. Roofing tiles are chiefly of two sorts, *plain tiles* and *pan-tiles*. (See those terms.) —Tiles of a semicylindrical form, laid in mortar, with their convex or concave sides uppermost, respectively, are used for covering ridges and gutters —*Paving tiles* are usually of a square form, and thicker than those used for roofing. A fine kind was made in former times, and used for paving the floors of churches and other important buildings. They were generally of two colours, and ornamented with a variety of elegant devices. They were highly glazed, and are often called *encaustic tiles*. They are also some-



Ornamental Paving Tiles

1 and 3 Haccombe, Devonshire. 2 Woodperry, Oxon. 4. Wherwell, Hants

times, though erroneously, called *Norman* tiles, for they belong to a much later period than the Norman era. Encaustic tiles, of beautiful forms and colours, have been again introduced.—*Dutch tiles*, for chimneys, are made of a whitish earth, glazed, and printed or painted with various figures. They are now seldom used.

TILE-CREASING.—Two rows of plain tiles placed horizontally under the coping of a wall, and projecting about $1\frac{1}{2}$ inch over each side, to throw off the rain-water.

TILING.—A square of tiling is equal to 100 superficial feet.

768 plain tiles,	6-inch gauge,	will	cover	1	square.
655 ,,	7 ,,	,,	,,	1	,,
576 ,,	8 ,,	,,	,,	1	,,
180 pan-tiles,	10 ,,	,,	,,	1	,,

A plain tile is $10\frac{1}{2}$ inches long, $6\frac{1}{4}$ inches wide, $\frac{5}{8}$ inch thick, and weighs 2 lbs. 5 oz.

A pan-tile is $13\frac{1}{2}$ inches long, $9\frac{1}{2}$ inches wide, $\frac{1}{2}$ inch thick, and weighs $7\frac{1}{2}$ lbs.

It takes 1 bundle of laths for 1 square of either plain or pan-tiling

700 plain tiles weigh 14 cwts.
180 pan-tiles weigh $7\frac{1}{2}$ cwts.

TILTING-FILLET.—A chamfered fillet of wood laid under slating where it joins to a wall, to raise it slightly, and prevent the water from entering the joint.

TIMBER.—1. That sort of wood which is squared, or capable of being squared, and fit for being employed in house or shipbuilding, or in carpentry, joinery, &c. We apply the word to standing trees which are suitable for the uses above mentioned, as a forest contains excellent *timber;* or to the beams, rafters, boards, planks, &c., hewed or sawed from such trees. But in the language of the customs, when a tree is sawn into thin pieces, not above 7 inches broad, it is called *batten;* when of greater breadth, such thin pieces are called *deal.* Timber is generally sold by the load. A load of rough or unhewn timber is 40 cubic feet, and a load of squared timber 50 cubic feet. In regard to planks, deals, &c., the load consists of so many square feet: thus, a load of 1 inch plank is 600 square feet. The most useful timbers of Europe are the oak, the ash, the Scotch pine, the larch, and the spruce fir; those of North America are the hiccory, the different species of pine, and some species of oak; those of tropical countries are the teak tree, the different species of bamboo, and the palm. *Wood* is a general term, comprehending under it timber, dye-woods, fancy woods, fire-wood, &c., but the word *timber* is often used in a loose sense for all kinds of felled and seasoned wood.—2. The body or stem of a tree.—3. A single piece or squared stick of wood for building, or already framed; one of the main beams of a fabric.

TIMBER BRICK.—A piece of timber of the size and shape of a brick, inserted in brick-work to attach the finishings to.

TIN-SAW.—A kind of saw used by bricklayers for sawing bricks.

TOO-FALL, or To-Fall.—A term used as synonymous with *lean-to.*

TOOLING.—In stone-cutting, a more perfect description of work than Random-Tooling (which see). In tooling, in place of working a draught from end to end of the stone, the workman, by moving his chisel laterally its own width at every stroke, forms a continuous flute across the stone. He thus works the flutes in successive lines, from an eighth to a quarter of an inch wide. Tooling is difficult to perform well, and unless well done it is very unsightly.

Tooth Ornament

TOOTH-ORNAMENT.—One of the peculiar marks of the Early English period of Gothic architecture. It consists of a pyramid, having its sides partially cut out, so as to have the resemblance of an inverted flower. It is generally inserted in the hollow mouldings of doorways, windows, &c.

TOOTHING.—Bricks or stones left projecting at the end of a wall, that they may be bonded into a continuation of it when required; also, a tongue or series of tongues.

TOOTHING PLANE.—A plane, the iron of which, in place of being sharpened to a cutting edge, is formed into a series of small teeth. It is used to roughen a surface intended to be covered with veneer or cloth, in order to give a better hold to the glue.

TOP BEAM.—The same as Collar-Beam.

TOP RAIL.—The highest rail in a piece of framing.

TORCH, *v.*—In plastering, to point the inside joints of slating laid on lath with lime and hair.

TORSELS.—The pieces of timber lying under the mantel tree. They are otherwise called *tassels.*

TORUS.—A large moulding used in the bases of columns. Its section is semicircular, and it differs from the astragal only in size, the astragal being much smaller. It is sometimes written *tore.* See woodcut, Column.

TOTE.—The handle of a plane.

TOUCH-STONE.—A black, smooth stone, or marble; so called from its employment in testing the quality of the precious metals, by the marks they leave when rubbed upon its surface. This sort of marble was extensively used in the sixteenth and seventeenth centuries for tombs. Henry Seventh's will directed that his tomb should be made "of the stone called *touche.*"

TOWER.—A lofty building, of a square, round, or polygonal form, consisting often of several stories, and either isolated or connected with other buildings. Towers may be classified according to their uses for defence, as monuments, or as attached to churches. Among the first are the donjons, and the towers which form part of the inclosures of castles, walled cities, towns, &c. Belonging to the second class are the round towers met with in Ireland, &c. But the greatest variety is to be found in the third class, the towers of cathedrals and churches of the middle ages. The towers belonging to the period of Saxon architecture are square and massive; those of the Norman style are sometimes round, but are generally square, and of rather low proportions, seldom rising much more than their own breadth above the roof of the church. In the Early English style there is a greater variety of design and proportion, and in the Decorated style this diversity is still greater. The magnificent church towers of the Perpendicular style form one of its leading beauties. These towers are seen in the greatest perfection in Somersetshire and the neighbouring counties. They are usually divided into stages by bands of quatrefoils, each stage being filled with large windows, frequently double. The angles have large buttresses, often ornamented with shafts and niches. The parapet is panelled and pierced, having lofty panelled and crocketed pinnacles at the angles, and lesser ones in the intermediate spaces. The towers of St. Mary's, Taunton, St. John's, Glastonbury, and St. Stephen's, Bristol, may be taken as the best types of this kind of tower. Many towers are finished with lofty spires, usually crocketed; and some by an octagonal stage, called a *lantern,* as at Boston, Fotheringay, and Newcastle-upon-Tyne.

TRABEATION.—The same as *entablature.*

TRACERY.—That species of pattern work, formed or *traced* in the head of a Gothic window, by the mullions being there continued, but diverging into arches, curves, and flowing lines, enriched with foliations. Also, the subdivisions of groined vaults, or any ornamental design of the same character, for doors, panelling, or ceilings.

TRAMMELS.—Elliptic compasses, an instrument for drawing ovals, used by joiners and other artificers. See p. 23.

TRANSEPT.—The transverse portion of a church built in the form of a cross; that part which is placed between the nave and choir, and extends beyond the sides of the area which contains these divisions, forming the short arms of the cross, upon which the plan is laid out. See woodcut, Cathedral.

TRANSOM.—A horizontal bar of stone or timber across a mullioned window, dividing it into stories; also, the cross-bar separating a door from the fanlight above it. See p. 156.

TRANSOM WINDOW.—A window having a cross-piece or transom.

TRAPEZIUM.—A plane figure contained by four straight lines, none of them parallel.

TRAPEZOID.—A plane figure contained by four straight lines, two of them parallel.

TREAD.—The horizontal surface of a step. See p. 196.

TREENAIL (commonly pronounced *trunnel*).—A cylindrical wooden pin.

TREES.—When felled, should be preserved from contact with the soil, and sheltered from the sun, p. 100.

TREFOIL.—An ornamental foliation much used in Gothic architecture in the tracery of windows,

Trefoils

panels, &c. It is of several varieties, but always consists of three cusps, the spaces inclosed between them producing a form similar to a three-lobed leaf.

TRIANGLE.—To find the area of, when the base and perpendicular height are given—Rule: Multiply the base by the perpendicular height, and half the product will be the area.—When two sides and the included angle are given. Rule: Multiply one side by half the other, and by the natural sine of the included angle.—When three sides are given. Rule: Add the three sides together, and from half the sum subtract each side separately; then multiply the half sum and the three remainders successively, and the square root of the last product will be the area.

TRIGLYPH.—An ornament used in the frieze of the Doric column, consisting of vertical angular channels or gutters separated by narrow flat spaces, and repeated at equal intervals. Each triglyph consists of two entire gutters or channels, cut to a right angle, called *glyphs,* and two half channels separated by three interstices, called *femora.* The Doric frieze consists of triglyphs and metopes.

TRIMMER.—A flat brick arch for the support of a hearth in an upper floor. It is turned from the chimney breast to a joist parallel to it, called a *trimmer-joist.* See p. 151.

TRIMMER-JOIST.—The joist against which the trimmer abuts.

TRIMMING-JOISTS.—The joists thicker than the common bridging-joists into which the trimmer is framed.

TRIMMING OF TIMBER.—The working of any piece of timber into the proper shape, by means of the axe or adze.

TRINGLE.—In architecture, a little square member or ornament, as a listel, reglet, platband, and the like, but particularly a little member fixed exactly over every triglyph.

TROCHILUS.—The same as *scotia.*

TROUGH GUTTER.—A gutter in form of a trough; an eaves-gutter.

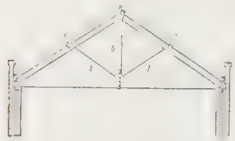
TROWEL.—A tool used by masons, plasterers, and bricklayers, for spreading and dressing mortar and plaster, and for cutting bricks so as to reduce them to the required shape and dimensions. Trowels are of various kinds, according to the different purposes for which they are used.

TRUNK of a Column.—The shaft or fust.

TRUSS.—A combination of timbers, of iron, or of timbers and iron-work so arranged as to constitute an unyielding frame. It is so named because it is *trussed* or tied together. The simplest exemplar of a truss is the principal or main couple of a roof, fig. 1, in which *a a,* the tie-beam, is suspended in the middle by the king-post *b,* to the apex of the angle formed by the meeting of the rafters *c c,*

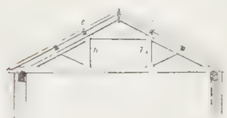
The feet of the rafters being tied together by the beam *a a*, and being thus incapable of yielding in the direction of their length, their apex becomes a fixed

Fig 1



point, to which the beam *a a* is *trussed* or tied up, to prevent its sagging, and to prevent the rafters from sagging there are inserted the struts *d d*. It is obvious that the office of the beam *a a*, and of the king-post *b*, could be perfectly fulfilled by a string, as they both serve as ties. There are other forms of truss suited to different purposes, but the conditions are the same in all—viz., the establishing of

Fig 2.



fixed points to which the tie-beam is *trussed*. Thus, in fig. 2, two points *e e* are substituted for the single one, and two suspending posts *b b* are required. These are called *queen-posts*, and the truss is called a *queen-post truss*. See PRINCIPLES OF TRUSSING, p. 136.

TRUSSED BEAM.—A compound beam composed of two beams secured together side by side with a truss, generally of iron, between them. See p. 149, Plates XL., XLI.

TRUSSED GIRDER. p. 149, Plates XL., XLI

TRUSSED PARTITION.—A partition the timbers of which are framed together in the form of a truss. See p. 155, Plate XLV.

TRUSSED ROOF.—The principles of trussing described, p. 136.

TRUSSING BEAMS.—System of Mons. Laves, p. 149.

TRYING PLANE.—A plane used after the *jack-plane*, for taking off or shaving the whole length of the stuff, which operation is called *trying up*. See PLANE.

TUCK POINTING.—Marking the joints of brick-work with a narrow parallel ridge of fine white putty

TUDOR FLOWER.—A trefoil ornament, much used in Tudor architecture. It is placed upright on a stalk, and is employed in long rows, as a crest or ornamental finishing on cornices, ridges, &c

Tudor Flower.

TUDOR STYLE.—Properly, the architecture which prevailed in England during the reign of the Tudor family, or from the accession of Henry VII. in 1485, to the death of Elizabeth in 1603. It thus includes the Elizabethan style, but in the common acceptation of the term, is generally restricted to the period which terminated with the death of Henry VIII., and may, perhaps, be most correctly designated as *late Perpendicular*. Its principal characteristics are the more constant use of the depressed, four-centred arch, and the profuse use of panelling, of fan-tracery vaulting, and of a peculiar dome shaped turret, instead of pinnacles. These characteristics are seen to advantage in Henry VII.'s Chapel, Westminster; St. George's Chapel, Windsor; and King's College Chapel, Cambridge, which may be taken as the true types of this variety of the Perpendicular style. In domestic architecture, the Tudor style presents a curious blending of the Gothic and the Italian, when the necessity no longer existed of consulting security against attack as a main object, but while as yet the old architectural ideas retained too strong a hold over the mind to be readily abandoned. The mansions erected in England in the latter part of Henry VII.'s and the early part of Henry VIII.'s reign, exhibit the character of what may be taken as the genuine Tudor style. They retain the castellated form outwardly, and have in general the moat and gatehouse; but the towers are without strength, and are evidently intended for ornament and show, rather than for defence. Small octagonal turrets flank the angles, and terminate in a kind of turret pinnacles, capped with an ogee-shaped dome, which has frequently a large finial and bold crockets. These turrets, with the richly ornamented stacks of brick chimneys, large square windows, divided into many lights by mullions and cross-bars or transoms, the extensive use of panelling and of the Tudor flower, and the very general use of brick as a building material, may be considered as the leading characteristics of the style before its admixture with foreign details. By the introduction of these, the Tudor style became materially altered, before the end of the reign of Henry VIII. the castellated form was lost, and it gradually passed into what is known as the Elizabethan style. See ELIZABETHAN STYLE.

TUMBLED IN.—The same as *trimmed*.

TUMOURS IN TREES.—Injurious to the wood, p 97.

TURNING PIECE.—A centre for a thin brick arch.

TUSCAN ORDER.—The simplest of all the five Roman orders, being nothing more than a ruder Doric. It has strength as its distinguishing characteristic. The shaft of the column, including the base and capital, is generally 7 diameters in height, and its upper diameter is diminished to 45 minutes, or to three quarters of the lower diameter. The entablature is less than two diameters in height The frieze recedes a little from the face of the archi trave, and neither of them have any ornament. The following table exhibits the proportions assigned to the different parts of this order by five distinguished writers:—

	Palladio.	Scamozzi.	[illegible]	Vignola.	Chambers.	[illegible]
Lower Diameter in minutes	[illegible]	[illegible]	60′	[illegible]	[illegible]	60′
[illegible]	[illegible]	[illegible]	45′	[illegible]	[illegible]	[illegible]
Height of the Col in diameters	7	7 30	6	[illegible]	[illegible]	6·54
Height of the Entablature	[illegible]	[illegible]	1 30	[illegible]·40	1·45	[illegible]
Height of Architrave	35½′	32′	30	25′	31½′	31
Height of Frieze	26′	39′	[illegible]	35′	31½′	[illegible]
Height of Cornice	43½′	41′	[illegible]	[illegible]	[illegible]	[illegible]

For an example of the Tuscan Order, see the woodcut under COLUMN.

TUSK TENON.—Described p. 151, Plate XLII., Figs. 2 and 4.

TYMPAN, TYMPANUM.—In architecture, the space in a pediment, included between the cornice of the inclined sides and the fillet of the corona. The term is also used to signify the die of a pedestal, and the panel of a door. The *tympan of an arch* is the spandrell.

TWISTED FIBRES.—In trees, render the wood unfit for the carpenter, p. 97.

U.

ULCERS in trees, p. 97

ULMUS. The elm tree. Description and uses of, p. 110.

UNDER-CROFT.—A vault under the choir or chancel of a church.

UNDERFOOT.—The same as *underpin* (which see).

UNDERPIN, *v.*—1. To support a wall, or a mass of earth or rock, when an excavation is made beneath it, by building up under it from the lower level. *To underset* and *to underfoot* are used in the same sense.

UNDERPINNING.—1. The act of bringing up a solid building, to replace soft earth or other material removed from beneath a wall or overhanging bank of earth or rock. In Scotland this process is called *goufing*.—2. Solid building substituted for soft materials excavated from under a wall, bank of earth, or mass of rock.

UNGULA.—In geometry, a part cut off from a cylinder, cone, &c., by a plane passing obliquely through the base and part of the curved surface. Hence it is bounded by a segment of a circle which is part of the base, and by a part of the curved surface of the cone or cylinder, and by the cutting plane.—It is so named from its resemblance to the hoof of a horse.

Ungula.

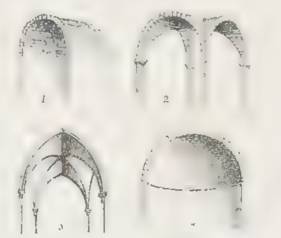
V.

VALLEY RAFTER.—The rafter in the re-entrant angle of a roof. See HIP ROOF, p. 91.

VANISHING POINT.—In perspective, the point in which an imaginary line passing through the eye of the observer parallel to any original line cuts the horizon. See p. 230, 231.

VASE.—The body of the Corinthian and Composite capitals. See DRUM and TAMBOUR.

VAULT.—A continued arch, or an arched roof, so constructed that the stones, bricks, or other material of which it is composed, sustain and keep each other in their places. Vaults are of various kinds, cylindrical, elliptical, single, double, cross, diagonal, Gothic, &c. When a vault is of greater height than half its span, it is said to be *surmounted*, and when of less height, *surbased*. A *rampant vault* is one which springs from planes



1. Cylindrical, barrel, or waggon vault. 2. Roman vault, formed by the [illegible] 3. G[illegible] vault. 4. [illegible]

not parallel to the horizon. One vault placed above another constitutes a *double vault*. A *conic vault* is formed of part of the surface of a cone, and a *spherical vault* of part of the surface of a sphere, as fig. 4. A vault is *simple*, as figs. 1 and 4 when it is formed by the surface of some regular solid, around one axis; and *compound*, as figs. 2 and 3, when compounded of more than one surface of the same solid, or of two different solids. A *groined vault*, fig. 3, is a compound vault, rising to the same height in its surfaces as that of two equal cylinders, or a cylinder with a cylindroid.

VAULTING SHAFT, VAULTING PILLAR.—A pillar sometimes rising from the floor to the spring of the vault of a roof; more frequently, a short pillar attached to the wall, rising from a corbel, and from the top of which the ribs of the vault spring. The pillars between the triforium windows of Gothic churches rising to and supporting the vaulting may be cited as examples.

VAULTS.—Method of dividing into compartments, p. 82.

VENEER.—A facing of superior wood placed in thin leaves over an inferior sort. Generally, a facing of superior material laid over an inferior material.

VENETIAN WINDOW.—A window of large size divided by columns or piers resembling pilasters into three lights, the middle one of which is usually wider than the others, and is sometimes arched.

VERANDA, VERANDAH.—An oriental word denoting a kind of open portico, or a sort of light external gallery in front of a building with a sloping roof, supported on slender pillars, and frequently partly inclosed in front with lattice-work. In India almost every house is furnished with a veranda, which serves to keep the inner rooms cool and dark.

VERGE-BOARDS.—See BARGE-BOARDS.

VERMICULATED WORK.—In masonry that in which the stones are so dressed as to have the appearance of having been eaten into or tracked by worms.

VERNIER.—A small moveable scale, p. 34.

VERSED SINE, OR HEIGHT OF AN ARC.—To find, the chord and radius being given, Prob. LXII. p. 17.

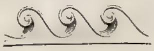
VERTICAL PLANE. p. 47, 229.

VESICA PISCIS.—A name given to a figure formed usually by the intersection of two equal circles cutting each other in their centres, but often also assuming the form of an ellipse or an oval. It is a common figure given to the *aureole*, or *glory*, by which representations of each of the three persons of the Holy Trinity and of the Blessed Virgin are surrounded in the paintings and sculptures of the middle ages. The form is also found in panels, the tracery of windows, and other architectural features, and is very common in ancient ecclesiastical seals.

VESTIBULE.—1. The porch or entrance into a house, or a large open space before the door, but covered. 2. A little antechamber before the entrance of an ordinary apartment.

VIGNETTE.—In architecture, ornamental carving in imitation of vine leaves.

VITRUVIAN SCROLL.—A name given to a peculiar ornament much used in classic architec-



Vitruvian Scroll.

ture. It is formed of a series of undulating scrolls joined together.

VITTA.—Ornament of a capital, frieze, &c.

VOLUTE.—A kind of spiral scroll, used in the Ionic and Composite capitals, of which it is a principal ornament. The number of *volutes* in the Ionic order is four; in the Composite, eight. There are also eight angular volutes in the Corinthian capital, accompanied with eight smaller ones, called helices.

VOMITORY.—An opening gate or door in an ancient theatre and amphitheatre, which gave ingress or egress to the people.

VOUSSOIR.—A stone in the shape of a truncated wedge which forms part of an arch. The under sides of the voussoirs form the intrados or soffit of the arch, and the upper side the extrados. The middle voussoir is termed the *key-stone*. See ARCH.

W.

WAGGON-HEADED CEILING OR VAULTING.—The same as *Cylindric vaulting* (which see).

WAINSCOT.—The timber-work that serves to line the walls of a room, being usually made in panels, to serve instead of hangings. The wood originally used for this purpose was a foreign oak, known by the name of *wagenschot*, and hence the name of the material came by degrees to be corrupted into *wainscot*, and applied to the work itself. Hence, also, the name *wainscot* is often applied to oak deal.

WALES OR WALING-PIECES.—The horizontal timbers serving to connect a row of main piles together.

WALL-STRING. p. 196.

WALNUT WOOD.—Properties and uses of, p. 111.

WARPING. See CASTING.

WARTS in trees detrimental, p. 97.

WASH-BOARD.—The plinth or skirting of a room.

WASTING.—In stone-cutting, splitting off the surplus stone with a wedge-shaped chisel, called a *point*, or with a pick. By either of these the faces of the stone are reduced to nearly plane surfaces, and it is said to be *wasted off*; in Scotland called *clouring*.

WEATHER, *v.*—To slope a surface, so that it may throw off the water.

WEATHER-BOARDING.—Boards nailed with a lap on each other, to prevent the penetration of rain and snow.

WEDGE.—To find the surface of. Rule: Find the areas of the rectangle, the two parallelograms or trapezoids, and the two triangles of which its surface consists, and add them together.—To find the solidity of a wedge. Rule: To twice the length of the base add the length of the edge, and multiply the same by the breadth of the base and by one-sixth of the perpendicular from the edge upon the base; the product will be the content.

WEIGHT OF ROOF-COVERING:—

			cwt	qrs.	lbs.		cwt.	qrs
1	square of	pan tiling will weigh. ..	7	2	0			
1	do.	plain tiling..... .... from	14	0	0	to	14	2
1	do.	countess or ladies' slating	6	0	0			
1	do.	Welsh rag or Westmoreland do..................	10	0	0			
1	do.	7 lbs. lead..	6	1	0			
1	do.	copper, 16 oz. or 1 lb. p. ft.	0	3	16			
1	do.	zinc cast, $\frac{1}{16}$ inch thick..	2	0	6			
1	do.	do. $\frac{1}{32}$ inch thick..	1	0	4			

WELL-HOLE, WELL.—In a flight of stairs, the space left in the middle beyond the ends of the steps. See p. 196.

WELSH-GROIN OR UNDERPITCH GROIN.—A groin formed by the intersection of two cylindrical vaults, of which one is of less height than the other.

WELSH LAYS.—In slating, slates measuring 3 feet by 2 feet.

WET ROT.—Causes of, p. 100.

WEYMOUTH PINE OR YELLOW PINE, called also AMERICAN WHITE PINE.—Properties and uses of, p. 118.

WHEEL-WINDOW. See CATHERINE WHEEL, and ROSE WINDOW.

WHIP-SAW.—A saw usually set in a frame for dividing or splitting wood in the direction of the fibres. It is wrought by two persons.

WHITE ANT destructive to timber, p. 105.

WHITE FIR OR WHITE DEAL.—The produce of the *Pinus abies* or Norway Spruce.—Properties and uses of, p. 117.

WHITE SPRUCE.—Properties and uses of, p. 118.

WHITE WALNUT.—Properties of, p. 111.

WHITE WOOD OR ALBURNUM of trees unfit for carpentry, p. 98.

WICKET.—A small door formed in a larger one, to admit of ingress and egress without opening the whole.

WILLOW, The.—Properties and uses of, p. 114.

WIMBLE.—An instrument used by carpenters and joiners for boring holes; a kind of augur.

WIND.—To cast or warp; to turn or twist any surface, so that all its parts do not lie in the same plane.

WIND-BEAM.—An old name for *collar-beam*.

WINDERS.—Those steps of a stair which, radiating from a centre, are narrower at one end than at the other.

WINDING.—A surface whose parts are twisted so as not to lie in the same plane. When a surface is perfectly plane it is said to be *out of winding*.

WINDING-STICKS.—Two slips of wood, each straightened on one edge, and having the opposite edge parallel. Their use is to ascertain whether the surface of a board, &c., *winds* or is twisted. For this purpose, one of the slips is placed across one end of the board, and the other across the other end, with one of the straight-edges of each upon the surface. The workman then looks in a longitudinal direction over the upper edges of the two slips, and if he finds that these edges coincide throughout their length, he concludes that the surface is *out of winding*; but if the upper edges do not coincide, it is a proof that the surface *winds*. See WINDING.

WINDING-STAIRS. p. 196.

WINDOW.—An opening in the wall of a building for the admission of light, and of air when necessary. This opening has a frame on the sides, in which are set moveable sashes, containing panes of glass. The sashes are generally made to rise and fall, for the admission or exclusion of air, but sometimes the sashes are made to open and shut vertically, like the leaves of a folding door.

WINDOWS AND WINDOW FINISHINGS. p. 187.

WINDOW-FRAME.—The frame of a window which receives and holds the sashes.

WINDOW-SASH.—The sash or light frame in which panes of glass are set for windows. See SASH.

WINDOW-SHUTTERS.—Hung to sink into the breast, p. 188.

WINDOW-SILL. See SILL.

WING.—A smaller part or building attached to the side of the main edifice.

WOOD. See TIMBER.

WOOD blighted by frost unfit for the carpenter, p. 98.

WOOD-BRICKS.—Blocks of wood of the shape and size of bricks, inserted in the interior walls of a building as holds for the joinery.

WREATHED STRING. p. 196.

X. Y. Z.

XYST, XYSTOS, XYSTUS. In ancient architecture, a sort of covered portico or open court, of great length in proportion to its width, in which the athletæ performed their exercises.

YELLOW PINE.—Description and uses of, p. 116, 118.

YEW, The.—Properties and uses of, p. 120.

ZIGZAG-MOULDING. The same as *chevron* and *dancette* (which see).

ZOCCO, ZOCLE, ZOCOLO.—A square body under the base of a pedestal, &c., serving for the support of a bust, statue, or column.

ZOOPHORUS. In ancient architecture, the same with the *frize* in modern architecture; a part between the architrave and cornice; so called from the figures of animals carved upon it.

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